

# Office of the Chief Scientist for Human Factors

## Human Factors Aviation Maintenance

Program Review  
FY03



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The Federal Aviation Administration Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100) directs an aviation maintenance human factors program that focuses on identifying human factors issues across all aspects of aircraft maintenance and inspection personnel. The Aviation Maintenance research program has maintained a focused research approach in four major components – skill development, organizational influences, human error, and maintainer proficiency.

The following report lists projects between October 1<sup>st</sup>, 2002 and December 31<sup>st</sup>, 2003 (Appendix I). These projects address requirements identified by the Federal Aviation Administration Flight Standards office (Appendix II). The intent of this report is to allow Federal Aviation Administration sponsors to determine whether their requirements have been satisfactorily addressed, allow investigators to receive feedback from Federal Aviation Administration sponsors and other interested parties, and to provide feedback to the AAR-100 aviation maintenance program manager on the quality of the research program. Basically, this document is a means of holding each group (sponsor, investigator, AAR-100 program manager) accountable to ensure that the program is successful.

To view projects, 3 - 34

To view requirements, 37 - 49

The FY03 funded projects had \$1,000,000 contract dollars and the proposed FY04 and FY05 projects will have an estimated \$700,000 contract dollars each fiscal year.

Address questions or comments to:

William K. Krebs, Ph.D.

# Appendix I

## Human Factors Aviation Maintenance

### FY03 Funded Projects

<u>Project Title</u>	<u>Page #</u>
Establishing Training Requirements for the General Aviation Inspection Training System (GAITS): A Computer Based Training Software	4
Do Language Barriers Result in Aviation Maintenance Errors?	9
Computational Vision Models and Occupational Vision Standards	14
An Analysis of the Visual Demands Associated with Aviation Maintenance Inspectors	19
A Demographic Profile of Nondestructive Inspection and Testing (NDI/NDT) Personnel: A Preliminary Report	24
Computer and Broadband Technology in the Aviation Maintenance Workplace	29
Evaluation of Broadband Applications to Aircraft Maintenance Safety: A Case Study of Goodrich Aviation Technical Services	34

# ESTABLISHING TRAINING REQUIREMENTS FOR THE GENERAL AVIATION INSPECTION TRAINING SYSTEM (GAITS): A COMPUTER BASED TRAINING SOFTWARE

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**Abstract:** General Aviation (GA) constitutes a significant, but often ignored, portion of the aviation system. It is crucial that GA be reliable if we are to ensure the safety of the overall air transportation system. The inspection/maintenance system, which is responsible for identifying and fixing defects, is a key component of this system. In response to this need, this paper reports task analyses of aircraft inspection operations at geographically dispersed GA facilities operated under the Federal Aviation Regulation (FAR) Part 91, 135, and 145. Recommendations forthcoming from this analysis will be used to devise a computer based inspection training program focused on improving the aircraft inspector's performance. This report briefly outlines activities pursued in Year 1 of the research. The introduction provides a brief background for the study, the next section outlines the methodology adopted, detailing the task analyses conducted.

## INTRODUCTION

Aircraft in the General Aviation (GA) environment have their maintenance scheduled initially by a team that includes the FAA, aircraft manufacturers, and start-up operators, although these schedules may be taken and modified to suit individual requirements and meet legal approval. In many cases the customer may follow a manufacturer's inspection program, which calls for 100 hrs. and a yearly inspection. Within these schedules, there are checks at various intervals, often designated as flight line checks; overnight checks; and A, B, C and, the heaviest, D checks. The objective of these checks is to conduct both routine and non-routine maintenance of the aircraft. This maintenance includes scheduling the repair of known problems; replacing items after a certain air time, number of cycles, or calendar time; repairing defects discovered previously, for example from reports logged by pilot and crew or from line inspection, or items deferred from previous maintenance; and performing scheduled repairs.

One of the areas reported in need of improvement is the human inspection of aircrafts, as this process has been widely reported as a cause of several errors/accidents in the aircraft maintenance industry (see FAA, 1991; FAA, 1993; Hobbs and Williamson, 1995 and the 1995 Continental Express crash). This problem has been attributed to a lack of well-defined inspection procedures for use by the aircraft maintenance industry. In response, the industry has developed ad-hoc measures and general guidelines to assist various personnel involved in the inspection process. This has resulted in various organizations developing their own internal procedures, which vary in their level of instruction/detail. Because of this situation, inspection procedures are not standardized across the industry.

Moreover, they are often not based on sound principles of human factors design.

The two goals that need to be achieved by a maintenance/inspection program are safety and profitability. While safety is of paramount concern, profitability can be realized only when safety is achieved economically. For human inspectors, this means that in addition to performing the inspection task, they have to be sensitive to both efficiency, the speed measure, and effectiveness, the accuracy measure, if they are to optimize their performance. The interrelationship between these performance measures and task factors, among others, is seen in Figure 1.

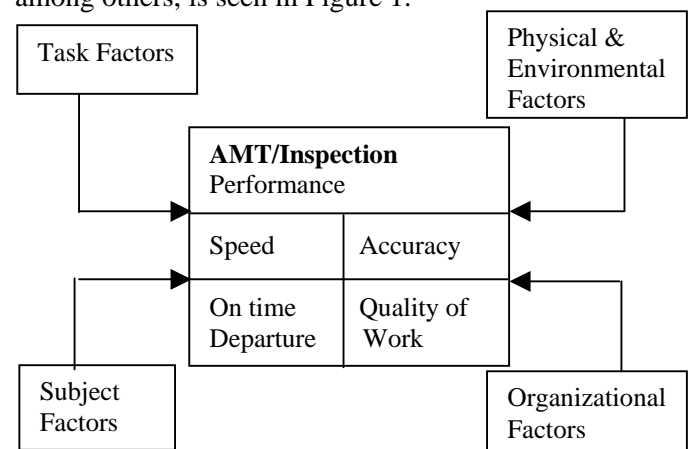


Figure 1. Factors Impacting Aircraft Inspection Performance

These two conflicting goals of safety and profitability are embodied in the inspection function in the form of *accuracy* and *speed*, respectively. Accuracy denotes detecting the defects that must be remedied for the safe operation of the aircraft while keeping false alarms to a minimum. Speed means the task must be performed in a timely manner without the excessive utilization of

resources. As can be seen, it is crucial that inspectors work not only effectively, that is, detect all potential defects, but also efficiently. The problem is further compounded in the GA inspection environment with its large differences in the size and type of maintenance facilities, organizational and physical environment, and inspector experience and technical skills.

In response to this need, a task analysis of inspection activities was conducted at representative GA facilities, with the research looking at the entire inspection process to identify training requirements, to help minimize inspection errors. The specific objectives of Year 1, were to analyze the inspection process at representative aircraft maintenance sites, develop a taxonomy of errors and identify training requirements to prevent the ill effects of the errors.

## METHODOLOGY

### Literature Review

As a first step a detailed literature review was conducted. The literature is available online and can be accessed through the following website ([http://www.ces.clemson.edu/~agramop/cur\\_act.htm](http://www.ces.clemson.edu/~agramop/cur_act.htm)). Figure 2 shows a screenshot of the database.

Figure 2. Screenshot of the database.

Following this step, the study analyzed the inspection process at representative GA aircraft maintenance sites, including the norms, information transfer procedures, guidelines and FAA-mandated procedures. Next, a detailed error taxonomy was developed to help classify the typical inspection errors. These errors were then analyzed and interventions identified to develop a standardized inspection process to minimize them. During this phase of the study, the researchers focused on the mechanic/inspectors, their respective supervisors, and the various entities they interact with. Following this step, recommendations were developed to support

improved inspection performance.

### Task Analysis of Inspection Operations at GA Facilities

A detailed task analysis of the operations was conducted using data collected through shadowing, observation, and interviewing techniques. The team partners at representative maintenance sites located within the continental US provided the research team with access to their facilities, personnel, and documentation and allowed the research team to analyze their existing inspection protocol at different times of the shift. The research team worked with the managers, line supervisor/shift foremen, and more than 100 inspectors and aircraft maintenance technicians. The research team visited sites with both light and heavy inspection and maintenance work governed by FAR Part 91, 135, and 145. The researchers conducted follow-up interviews with the various personnel involved to ensure that all aspects of the inspection process were covered. These interviews discussed issues concerning the tasks they were undertaking or had just performed and general issues concerning their work environment, both physical and organizational.

The study was initiated with a meeting between the members of the research team and the airline personnel to outline its objectives and scope. The objective was to identify human-machine system mismatches that could lead to errors through shadowing, observing, and interviewing techniques. The goal of the task analysis, which was to understand how the existing system works, was achieved using a formal task analytic approach (Gramopadhye and Thaker, 1998). The first step in this approach is to develop a description of the task, outlining in detail the steps necessary to accomplish the final goal. While various formats can be used to describe a task, this study used a hierarchical one in conjunction with a column format. Figure 3 show a sample hierarchical task analysis (HTA) used for the inspection process. Each step was later described in detail in a column format similar to that used by FAA (1991). This column format identified the specific human subsystem--attention, sensing, perception, decision, memory, control, feedback, communication, and output--required for the completion of each step (Table 1). Using this format enabled the analysts to identify clearly the specific cognitive and manual processes critical in the performance of the tasks, identifying the opportunities for error. As an example, for Sub-Task 1.3, Memory was identified as a critical sub-process; observable errors occurring over various shifts at different sites were tabulated for all technicians for this specific sub-

component (see data in Table 2.). Follow-up interviews, questionnaires and observational techniques were used to identify and isolate error-causing mechanisms. This data was later mapped using Rouse and Rouse's (1983) error taxonomy to identify the error genotypes (Table 3). Having this information, expert human factors knowledge was applied to the sub-task to identify specific interventions (e.g., provide job-aids) to minimize the negative effects due to specific training needs to improve performance on the sub-task.

Following the analysis of inspection, a comprehensive error classification scheme was developed to classify the potential errors by expanding each step of the task analysis into sub-steps and then listing all the failure modes for each, using the Failure Modes and Effects Analysis (FMEA) approach (Hobbs and Williamson, 1995). These represent the error phenotypes, the specific, observable errors providing the basis for error control. Error prevention and the development of design principles /interventions for error avoidance rely on genotype identification, associated behavioral mechanism and system interaction. The phenotypes were characterized by the relevant aspects of the system components (e.g., human, task, environment, etc.) with which they interact. The resulting list of phenotypes, error correctability and type, and the relevant error shaping factors, enable designers to recognize these errors and design control mechanism to mitigate their effects. For this purpose, Rouse and Rouse's (1983) behavioral framework was used to classify errors during an inspection process and to identify the genotypes associated with each phenotype. This methodology yielded the mechanism of error formation within the task content. This error framework, which classifies human errors based on causes as well as contributing factors and events, has been employed to record and analyze human errors in several contexts such as detection and diagnostics, trouble-shooting and aircraft mission flights.

## TRAINING REQUIREMENTS

Following observations and discussions with various inspectors and a detailed task analysis of the inspection processes, training recommendations were identified and mapped using The American Society for Nondestructive Testing (2001) requirements (Table 4) for the following four representative tasks: (1) Cabin and under floor inspection; (2) Landing gear inspection; (3) Inspection of Aileron; and (4) Inspection of elevator. Having performed the task analyses, it now forms as the basis for developing a computer based inspection training program to support inspectors in the GA environment

(GAITS – Figure 3). Moreover it will be used to establish the content, methods, and delivery system for the training program.

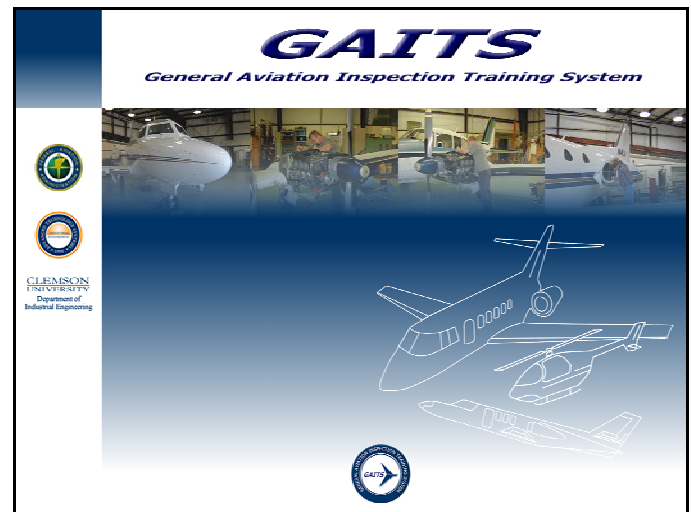


Figure 3. GAITS logo screen

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Table 1: Sample Task Analysis of the Inspection Process

TASK DESCRIPTION	Task Analysis									OBSERVATIONS	CONTENT
	A	S	P	D	M	C	F	O			
1.0 INITIATE INSPECTION											
1.1 Use Documentation to Plan Task											
1.1.1 Read Documentation	X	X								Read the work card correctly.	Consists information on: <ul style="list-style-type: none"><li>Identifying the correct document.</li><li>Reading the correct information.</li></ul>
1.1.2 Plan task, strategy and mental model	X	X	X		X					Did not plan the task appropriately. (E 1.1.2.2) Planned the search strategy. Created an appropriate mental model.	Consists information on: <ul style="list-style-type: none"><li>tasks</li><li>strategies</li><li>mental models</li><li>planning the appropriate task</li><li>planning the appropriate strategy</li><li>creating appropriate mental models</li></ul>

A: Attention

S: Senses

P: Perception

D: Decision Making

M: Memory

C: Control

F: Feedback

O: Others

Table 2: Sample Error Taxonomy

TASK DESCRIPTION	ERRORS	OUTCOME	TRAINING NEEDS
<b>1.0 INITIATE INSPECTION</b>			
<i>1.1 Use Documentation to Plan Task</i>			
1.1.1 Read Documentation	E1.1.1.1 Does not have the correct documentation (EC1). E1.1.1.2 Does not have the documentation (EC 1). E1.1.1.3 Does read the document incorrectly (EC 6). E1.1.1.4 Does not know how to read the document (EC 5). E1.1.1.5 Does not interpret the document correctly (EC 3).	Does know to locate, read and interpret the correct documentation.	Are the inspectors trained to locate the correct documentation? Are the inspectors trained to read and interpret the correct documentation?

EC1 – Observation of system state

EC2 – Choice of hypothesis

EC3 – Testing of hypothesis

EC4 – Choice of goal

EC5 – Choice of procedure

EC6 – Execution of procedure

Table 3: Mapping errors using Rouse's taxonomy.

EC 1 TYPE ERROR	TRAINING NEEDS
E1.1.1.1 Does not have the correct documentation (EC1). E1.1.1.2 Does not have the documentation (EC 1).	Are the inspectors trained to locate the correct documentation?
E1.1.3.1 Does not know about the different types of defects (EC 1). E1.1.3.2 Does not know all the defects (EC 1). E1.1.3.3 Does not know about the criticality of defects (EC 1). E1.1.3.4 Does map the defects with criticality incorrectly (EC 1). E1.1.3.5 Does not know how often the defects occur (EC 1). E1.1.3.6 Does not know about the location of the defects (EC 1). E1.1.3.7 Does map the defects with location incorrectly (EC 1).	Are the inspectors trained to detect the different types of defects? Are the inspectors trained to map the defects with criticality? Are the inspectors trained to determine the probability of the occurring defects? Are the inspectors trained to locate the defects correctly?

Table 4: Mapping training needs using The American Society of Nondestructive Testing (ASNT) requirements.

Training Content	ASNT Specifications			Training Methods	Training Delivery Systems
	Level 1	Level 2	Level 3		
3.1.3 <ul style="list-style-type: none"> <li>Consists information on how to inspect an aircraft cable pulley.</li> <li>Consists information on the tools required to inspect an aircraft cable pulley.</li> </ul>	4.0 Equipment 6.0 Visual testing to specific procedures	5.10 Position	1.3 Test object characteristics 4.0 Interpretation/Evaluation		
3.1.4 <ul style="list-style-type: none"> <li>Consists information on how to inspect the cables.</li> <li>Consists information on the tools required to inspect the cables.</li> </ul>	4.0 Equipment 6.0 Visual testing to specific procedures	5.10 Position	1.3 Test object characteristics 4.0 Interpretation/Evaluation		
3.1.5 <ul style="list-style-type: none"> <li>Consists information on how to identify the radar cable.</li> <li>Consists information on how to inspect the radar cable.</li> <li>Consists information on the tools required to inspect the radar cable.</li> </ul>	4.0 Equipment 6.0 Visual testing to specific procedures	5.10 Position	1.3 Test object characteristics 4.0 Interpretation/Evaluation		



# DO LANGUAGE BARRIERS RESULT IN AVIATION MAINTENANCE ERRORS?

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The existence of maintenance and inspection personnel whose native language is not English suggests that language barriers may be causing performance errors. This project examines whether such errors exist, what patterns characterize these errors, what their contributing factors are and how effectively we can mitigate these errors. Any language errors would be communication errors by definition, so first we reviewed models of communication to search for characteristic error patterns. We identified two primary communication types relevant to aviation maintenance: synchronous communications (largely verbal and informal) and asynchronous communication (largely written and formal). We then analyzed several error databases (e.g. ASRS) and found that both the contributing factors and the use of recovery mechanisms were different for the two error types. Next, we analyzed survey data from 113 aircraft operators, covering their English speaking/reading abilities and use of mitigation strategies. There were significant differences across four world regions in the incidence of these two sets of factors. Neither of these data sources emphasized maintenance, so to discover more refined patterns of error, contributing factors and mitigation strategies, we conducted a series of focus groups at maintenance organizations. The patterns found were grouped, as expected, into synchronous and asynchronous. We developed classified lists of contributing and mitigating factors, which will be used in subsequent stages to quantify error incidence and test the effectiveness of mitigation strategies.

## INTRODUCTION

Outsourcing is a preferred corporate strategy for reducing nonessential costs and focusing an organization on its core business (Cant and Jaynes, 1998). In aviation maintenance, outsourcing has been advocated and widely used, as it avoids tying up capital in maintenance facilities, and can reduce costs by opening the airline's maintenance operation to outside competition. One potential impact of such outsourcing is that there are more interfaces within the system, each of which represents an opportunity for error. The "system" without outsourcing includes the aircraft itself, the airline and the regulatory agency (e.g. the FAA). However, with outsourcing, a fourth organization is added to the system: the Maintenance/Repair Organization (MRO). Drury, Wenner and Kritkauskys (2000) provided models of these interactions and examined potential and actual error sources from using MROs. Data collection at a number of domestic and foreign MROs did indeed show a potential for increased errors, but little evidence of errors in practice.

Sparaco (2002) sees the formation of global MRO networks involving US and foreign airlines, as well as repair stations. In addition to offshore MROs, there are many within the USA where non-native English speakers form part of the labor pool. The difficulty of moving between languages creates an additional potential for error. The language of aviation is primarily English, both in operations and in maintenance. Aviation Maintenance Technicians (AMTs) must pass their examinations in English, and maintenance documentation in use at the Federal Aviation Administration (FAA) approved facilities is in English. This poses a second-language or translation burden for Non-Native English Speakers (NNESS) that can potentially increase their

workload, their performance time or their error rate, or even all three measures.

In a 2001 report to the Secretary of Transportation by the Aircraft Repair and Maintenance Advisory Committee, many of these issues were raised in considering changes to the domestic and foreign FAR Part 145. They recommended that:

*"The FAA should establish a method for determining whether language barriers result in maintenance deficiencies."*

This project is a direct response to these concerns that NNESS, in repair stations in the USA and abroad, may be prone to an increased error rate that could potentially affect airworthiness.

## MODELS OF COMMUNICATION

Communication is defined as "a dynamic and irreversible process by which we engage and interpret messages within a given situation or context, and it reveals the dynamic nature of relationships and organizations" (Rifkind, 1996). Communication can be formal or informal. Davidmann (1998) made a distinction between formal and informal communication, where formal communication implies that a record is kept of what has been said or written, so that it can be attributed to its originator. On the whole, written communications are formal. Most on-the-job communication is informal, unwritten, and sometimes even unspoken. An important distinction made in communication theory is the temporal aspect: communication is either synchronous or asynchronous. In aviation maintenance, synchronous communication is typically verbal, e.g. conversations or PA

announcements, while asynchronous communication is typically written, e.g. work documentation or placards. In the context of aviation maintenance and inspection, communication has been the most frequent aspect studied since the human factors movement began there in the early 1990's (Taylor and Patankar, 2000).

The fundamental function of communication is to deliver a message from one human being to another. In almost every aspect of aviation work, communication also fulfills a secondary role as an enabler (or tool) that makes it possible to accomplish a piece of work (Kanki and Smith, 2001). Based on examination of accident investigations and incident reports, Orasanu, Davision and Fischer (1997) summarized how ineffective communication can compromise aviation safety in three basic ways:

1. Wrong information may be used.
2. Situation awareness may be lost.
3. Participants may fail to build a shared model of the present situation at a team level.

Communication models in the form of generally simple diagrams are important in helping people to understand the concept and process (Wideman, 2002). Kanki and Smith (2001) state that human communication always takes place within a set of contexts, such as a social context, a physical context and/or an operational context. Compared to some other work settings, the aviation operational context is relatively structured by standard operating procedures that organize task performance. Figure 1 presents a communication model we synthesized from our literature review.

Based on basic communication theories, a communication process is composed of *the sender/receiver* (e.g. people, manuals, computers, etc.), *the message* (e.g. information, emotions, questions, etc.), *the medium* (e.g. speech, text, sensory, etc.), *filters/barriers*, *feedback*, etc. (Kanki and Smith, 2001; Griffith, 1999).

Fegyveresi (1997) summarized many variables that influence communication, such as workload, fatigue, personality traits, gender bias, standard phraseology, experience level, vocal cues, etc. Language and cultural diversity can intensify differences and confusions in communication, but a language barrier does not necessarily result in unsafe cockpit operations (Merritt and Ratwatte, 1997). In order to eliminate or at least minimize potential ambiguities and other variances, people establish rules regarding which words, phrases, or other elements will be used for communication, their meaning, and the way they will be connected with one another. The aggregation of these rules is known as a "protocol." There are four types of protocol related to flight and aircraft safety (Rifkind, 1996a&b): verbal, written, graphical, and gestural protocols. According to Rifkind (1996a&b), the only verbal protocol that has been established throughout aviation, including maintenance, is the use of English as the standard language. This was done when the International Civil Aviation Organization (ICAO) was established in 1944.

## CURRENT DATA SOURCES

Before field data is collected on language-related maintenance and inspection errors, existing databases need to be searched for relevant reports of such errors. The most useful of these were the NASA/FAA Aviation Safety Reporting System (ASRS) and the Accident/Incident Data System (AIDS). Our main interest was in maintenance and inspection errors, but few were reported in the databases studied. Hence, our objective changed to include all language-related errors, whether by flight crew, ATC, cabin crew or ground crew. This decision was in line with our literature search, which we broadened to include all communication errors. With a large enough set of aviation-related language errors, we can form more general models, of which maintenance and inspection errors will be a specific instance.

Based on a preliminary reading of about 60 incident reports, a taxonomy was developed of error manifestations, causal factors and recovery mechanisms. Some entries in this taxonomy reflect the earlier analysis by Orasanu, Davision and Fischer (1997), although we have tried to separate contributing factors from recovery mechanisms. This preliminary reading also found likely key words for searches. Two keyword searches were made of the ASRS and AIDS databases. The first was on "English" and the second on "Language." We classified 684 incidents by *error type*, *contributing factor*, and *recovery mechanism*. Details are not presented here due to space limitations.

The main division of error types was between synchronous and asynchronous communication. Within these, a relatively fine classification was made by the roles of the two communicators, e.g. flight crew with ground crew. This classification was eventually collapsed into four categories. Note that "language" was used to refer to two items. Language could mean the actual language used (e.g. French, Spanish, Chinese, English) or the choice of words/phrases (e.g. listener expected one term but communicator used what was incorrectly thought to be a synonym). Some of the communication channels themselves were poor, classified here as low signal/noise ratio. In many cases, the report mentioned that at least one of the communicators was inexperienced, for example an American crew's first flight for some years into a Mexican airport.

The analysis of the ASRS and AIDS databases used a cross-tabulation technique developed by Wenner and Drury (2000) to show significant and often interesting conclusions in Figure 2 and Figure 3. When the error locus was classified by the roles of the communicators, differences in contributing factors and recovery mechanisms were seen. Our four categories of causal factors gave roughly equal counts in the databases, showing that the use of other than a native language was an important causal factor in these errors. This contributing factor appeared to be distributed across error loci, except for asynchronous communication, where it was under-represented. In fact, for asynchronous communication as a whole, native language and low signal/noise ratio were under-represented factors, while unclear terminology was over-represented. For recovery, asynchronous communication had the least opportunity for recovery mechanisms. In particular,

the repetition useful in synchronous communications was not usually fruitful.

The characteristics of maintenance communications errors found here (asynchronous, terminology-related, few recovery mechanisms) helped to set the stage for our direct measurement of these errors from maintenance participant interviews and questionnaires.

From September 2002 to January 2003, an international corporation surveyed a large number of airlines throughout the world concerning their use of English and other languages in flight operations and maintenance operations. The database used was based on a large sample ( $n = 113$ ) of airlines, approximately evenly divided between North America, Europe, Asia and the rest of the world. Analysis of the use of English in written and spoken communications showed that English is spoken and read at a high level in North America, and to a large extent (75% or so) in Europe. In contrast, Asia and the other countries have about 50% of users able to work with written English effectively, and about 30-40% able to work with spoken English in the same way. The data from each level of English Speaking/Reading ability were analyzed separately using one-way ANOVAs among the four regions. All levels showed significant differences between regions.

The airlines cope with any potential problems through a number of means, including document translation, and conducting training and meetings in native languages. We have found that in Europe and North America, such strategies were infrequently used, presumably because most mechanics speak English, even if that is not their native language. In contrast, Asia and the rest of the world make significant use of these strategies. Translation of documents was not a common strategy, except for Asia, where 17% of airlines translated Task Cards and 60% translated Engineering Orders. Comparable figures were about 4% and 20% of airlines in other parts of the world, and almost nobody translated the Maintenance Manual. The strategy of using the native language in speaking was widely seen, with almost all Asian airlines and most airlines in other non English-speaking countries conducting meetings and maintenance training in languages other than English. However, this may represent a mismatch to documentation used in the same task that typically remained in English.

We expected that those airlines with low levels of English-reading ability would adopt some mitigating strategies in using the original documents (i.e. modification into AECMA Simplified English, translation into their native language). However, when using the Maintenance Manual, 7 out of 8 kept the original documents in English without any modification or translation, while only one airline modified/rewrote it in English. When using the Structural Repair Manual, 6 out of 8 airlines did not make any modification or translation. For those airlines with a low level of English-speaking ability, 100% conducted Onsite Maintenance Training in a language other than English (i.e. the native language). In Meetings, 10 out of 12 airlines used another language, while the remaining two used both English and another language. Again, during Casual Talking, none of the airlines used English.

## FOCUS GROUPS ON LANGUAGE ERRORS

While the analysis of archival data in the above section could provide some insight into language errors in maintenance, such data were not collected for that purpose (c.f. Drury 1995). More direct data collection involves the use of questionnaires and interviews specifically on the theme of language errors in maintenance. However, before we can ask sensible questions, we must have valid information on the types of errors involved. We collected such data from focus groups at MROs in different countries. So far (May 2003), we have run five such focus groups, three at US-based MROs and the other two at UK-based MROs.

A focus group gathers people together to discuss the issue at hand via moderator questions and group discussions. Data are gathered through observations and conversations with participants. Focus groups are particularly appropriate for use in exploratory studies when little is known about a population or phenomenon. According to Albrecht et al. (1993), data collected in focus groups may be more ecologically valid than methods that assess individuals' opinions in a relatively asocial setting, given that language errors are social events involving the interaction of participants and the interplay and modification of ideas.

We used focus groups of people at MROs drawn from AMTs, supervisors, engineers and QA specialists. Each interview lasted about 45 minutes. Our introductory statement (after introductions, ground rules and assurance of anonymity) was:

“We are helping the FAA to reduce errors in aviation maintenance and inspection. Our aim is to find improved ways of performing maintenance and inspection jobs. One issue has been that although English is the primary language of aviation, many people do not have English as their native language.”

Then, the focus groups discussed approximately ten questions with the principal investigator as moderator. When we had transcribed the data, we compared the transcripts with our notes to look for patterns of maintenance language errors or events under four headings.

1. Error types/patterns
2. Potential error detection points in the maintenance process.
3. Factors predisposing to language errors
4. Factors potentially mitigating language errors

From these lists, we were able to see the functions of aircraft maintenance and inspection (see Drury, Shepherd and Johnson, 1997) and where language errors could arise. **Table 1** represents our current characterization of these situations where their errors could arise, presented within a task sequence framework. We found the following patterns of error in both verbal (synchronous) and written (asynchronous) communication.

### Verbal (Synchronous)

1. AMT unable to communicate verbally to the level required.

2. AMT and colleagues/supervisors have poorly matched models of their own and each other's English ability.
3. Native English speakers with different regional or non-US English accents (e.g. UK, India, Caribbean) prevent adequate communications.
4. AMTs unable to understand safety announcements over the PA system.

#### Written (Asynchronous)

5. AMT unable to understand safety placard in English.
6. AMT unable to understand written English documentation.
7. Foreign documentation poorly translated into English.

While the patterns are still being refined as further data is collected, and may eventually exhibit more of a hierarchical structure, they were reasonably consistent between the focus groups studied.

Table 2 shows the predisposing and mitigating factors identified in the focus groups. They are classified in terms of the SHELL model of human factors in aviation (Easterby, 1967).

#### **NEXT STEPS**

The first phase of our project was to find the patterns of language errors, provided there is evidence that they exist. Our analysis of communication models and the company database has shown the potential for language errors by showing that responses to language differences may not always keep pace with the need for such interventions. The ASRS database analysis showed some actual errors, although these were mainly in the flight operations domain more likely to be reported to ASRS. Patterns in this data showed that maintenance language errors were largely asynchronous, while related to terminology and had few recovery mechanisms.

The five focus groups tested so far have refined our conclusions. We now have ample evidence that language errors exist, although there are recovery mechanisms and mitigating factors. The patterns found were numerous, and certainly not limited to asynchronous communication. Although documentation was an important source of difficulty, there were other patterns in verbal communication, including unexpected ones of regional accents of native English speakers. We were also able to further document the time course and propagation of errors, including error detection points and interventions. In an industry as heavily regulated as aviation maintenance, there are a number of barriers to error propagation (c.f. Reason, 1990), including the initial work assignment and inspection by a different person.

The characteristics of language errors found so far in maintenance will be refined as more focus group data is collected, but the agreement reached to date suggests that a few overall patterns may account for most of the potential errors. In subsequent years of this project, we will be collecting field data to estimate the prevalence of the patterns we have derived. This will be done using direct data collection in several regions of the world, for example those

used in our analysis of the company database. We will also use our methodology of comprehension tests of workcards (e.g. Chervak, Drury and Ouellette, 1996; Drury, Wenner and Kritkauskys, 1999) to test the effectiveness of intervention strategies. These include use of Simplified English, full translation, use of an English-speaking coach and provision of a local language glossary. In this way, we will be able to make recommendations to both MROs and regulatory bodies for the effective reduction of language errors.

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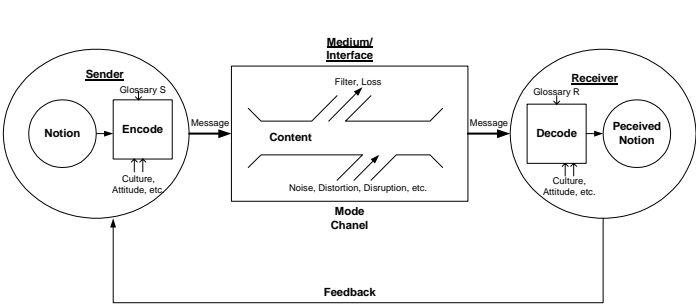


Figure 1. The Communication Model Synthesized from Literature Review (Wideman, 2002; Threnholm, 1986; McAuley, 1979; Johnson, 1972,etc.)

Function	Language Error Detection
Setup	<ul style="list-style-type: none"> <li>AMT may appear perplexed, or may agree with everything said.</li> </ul>
Task Performance	<ul style="list-style-type: none"> <li>AMT may ask for assistance or clarification.</li> <li>AMT may close access prematurely (i.e. before buyback)</li> </ul>
Buyback	<ul style="list-style-type: none"> <li>Physical error may be detected.</li> <li>AMT may not understand inspector's questions.</li> </ul>

Table 1. Language Errors Arising in a Task Sequence Framework

SHELL Category	Predisposing Factors	Mitigating Factors
Software (procedures)	<ul style="list-style-type: none"> <li>Task complexity</li> <li>Instruction complexity</li> </ul>	<ul style="list-style-type: none"> <li>Document translation</li> <li>Consistent terminology</li> <li>Good document design</li> </ul>
Hardware (equipment)	<ul style="list-style-type: none"> <li>Limitations of communication channel, e.g. radio, PA</li> </ul>	<ul style="list-style-type: none"> <li>Use of aircraft as a communication device: "show me"</li> </ul>
Environment	<ul style="list-style-type: none"> <li>Time pressure prevents AMT from querying others</li> </ul>	
Liveware (individual)	<ul style="list-style-type: none"> <li>Inadequate written English ability</li> <li>Inadequate English ability</li> <li>Reversion to native language under stress</li> </ul>	<ul style="list-style-type: none"> <li>Job familiarity</li> <li>Comprehension tests for AMTs</li> <li>Certify AMT for specific jobs</li> </ul>
Liveware (inter-communication)	<ul style="list-style-type: none"> <li>Unwillingness of AMT to expose their lack of English</li> <li>Time pressure</li> </ul>	<ul style="list-style-type: none"> <li>Translator available</li> <li>Assign AMTs to job based on English ability</li> <li>Team AMT with native English speaker</li> </ul>

Table 2. Predisposing and Mitigating Factors Identified in the Focus Groups

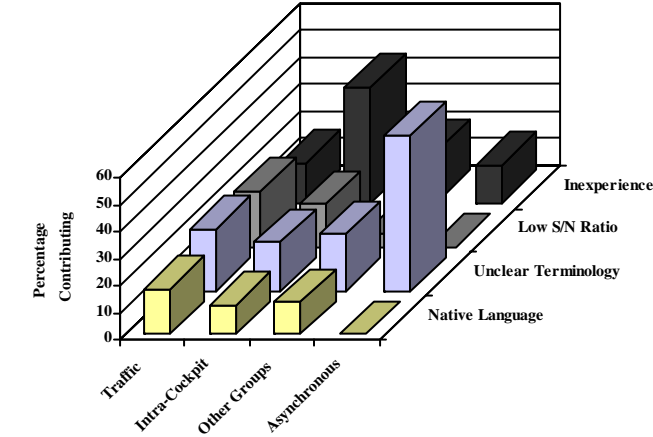


Figure 2. Pattern of Contributing Factors across Error Loci

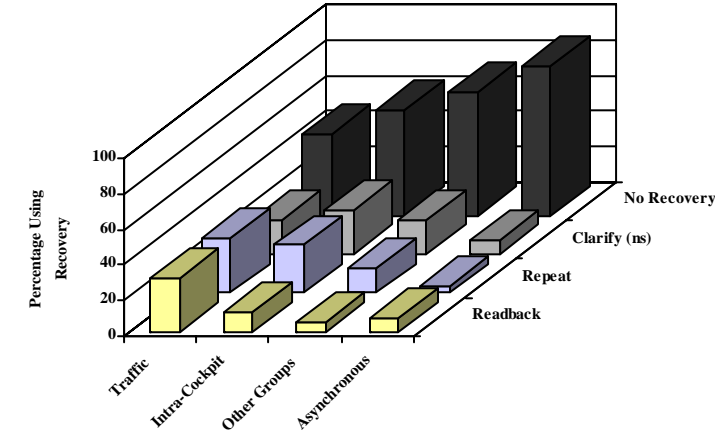


Figure 3. Pattern of Recovery Attempts across Error Loci

# COMPUTATIONAL VISION MODELS AND OCCUPATIONAL VISION STANDARDS

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**Background:** We describe a methodology that may be used to write uniform and universally accepted occupational vision standards. A simple image discrimination model is first calibrated using stimuli representative of airframe and powerplant cracks. It is then used to predict the visibility of simulated cracks of different lengths and widths. Visual acuity declines are simulated using a gaussian blur function on the crack images. Crack width is shown to be a salient cue to crack detection. Using this modeling technique we show when acuity declines begin to significantly effect performance. Future research will validate model predictions with human psychophysical data.

## INTRODUCTION

In a recent review of the occupational vision standards literature, Beard et al. (2002) found that the majority of occupational vision standards are not empirically substantiated, and appear to be arbitrarily decided. A few standards have been empirically defined. For example, to define a visual acuity standard for police officers, Sheedy (1980) measured the size and working distance of the critical visual details for a representative task. Visual acuity standards have also been defined for police officers (Good, 1987; 1996), basket weavers (Good et al., 1996) and firefighters (Padget, 1989) using blurring lenses to reduce acuity while measuring performance on a job relevant task. Finally, Mertens et al. (2000) measured performance in color weak individuals on simulated ATC tasks to set an empirically defined color vision standard.

Currently no general standard exists in the aviation industry for the visual qualifications of maintenance inspectors. Some aircraft maintenance facilities have developed their own vision qualification programs, highlighting the need for a uniform and universally accepted set of vision standards that would apply to all aircraft non-destructive inspection and testing

(NDI/NDT) personnel. It is difficult, if not impossible, to eliminate human error in the process of inspection. Therefore interventions must be developed to reduce these errors and make the process more error-tolerant. Since visual inspection represents 80% of all aviation maintenance inspection tasks (Goranson & Rogers, 1983), one mitigation strategy is to define vision standards for this vision-intensive, safety-critical occupation.

In this paper we apply a novel methodology toward defining an empirically based visual acuity standard for a representative task performed by aircraft maintenance personnel who do NDI/NDT and visual inspection. Computational models of human vision can make an important contribution to occupational vision requirements. One application of these models has been as image quality metrics, an application in which there are two images, an original image and a reconstructed version following image compression. The model predicts discriminability of the two images and thus the visibility of the compression artifacts (Watson, 1983). These discriminability models have also been used to predict object detection in a complex background, such as camouflaged military tanks (Rohaly et al.,

1997) and simulated aircraft on a runway (Ahumada & Beard, 1997).

To obtain an estimate of a visual acuity standard using image discrimination models, we follow a multi-step process. First, we calibrate the model for stimuli representative of airframe and powerplant cracks that are clear and blurred. We use a subset of the standard Modelfest images, whose contrast thresholds have been measure in a number of laboratories to calibrate the model. Second, we use the calibrated model to predict the visibility of simulated cracks of different lengths and widths as a function of blur, simulating reduced visual acuity in the image, rather than with blurring lenses, so that the image characteristics are exactly known. This provides an estimate of how much contrast sensitivity is lost by blur, so that if the tolerable loss in contrast sensitivity can be specified, the corresponding visual acuity is then specified. In support of the model's accuracy, we plan to obtain human psychophysical measurements to validate the simulated crack predictions. In addition, we will use the model to compare the simulated crack predictions to predictions for actual crack images in a natural aircraft scene. And finally, we will validate the natural scene predictions with human in the loop data. In this paper we report the results for the first two steps of this process.

The purpose of this paper is threefold. (1) To introduce a new methodology for determining occupational vision requirements. (2) To present the technique used for model calibration. (3) To run the model on simulated crack images over a range of widths and lengths at different levels of visual acuity.

## METHODS & RESULTS

### *A Representative Defect*

Aircraft inspection is a complex process, requiring many tasks, skills, and procedures. Its main purpose is the detection of discontinuities such as cracks<sup>1</sup> within the airframe and powerplant regions of the aircraft. Because these cracks may be very small and of low contrast, good visual acuity is likely to be involved in their detection. Visual acuity refers to a measure of spatial resolution of a person's vision for a high contrast, static image. After consulting with domain experts, we chose crack detection as the representative task in which to model.

### *A Simple Model*

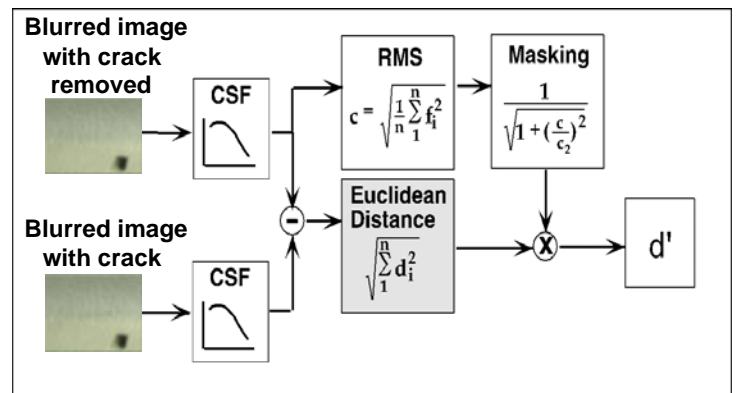


Figure 1. Schematic of an image detection model

Figure one's upper image is the background image and the lower image is the background-plus-defect image. The two input images (contrast images) enter the visual system, where they are filtered by a difference of gaussian blurring function. The difference of the images is calculated after which two standard deviations are computed; the first represents the root mean square error of the background image, which

<sup>1</sup> A crack may be defined as "A planar breach in continuity in a material" (Hellier, 2001). They are typically caused by two surfaces being overlaid at a boundary.

is assumed to be the masker and the second is the standard deviation of the defect pixel contrast. This generates a masking curve in which the masking contrast is determined by  $c^2$ . The product of these outputs represents the predicted sensitivity or the just noticeable difference of the crack defect.

Image discrimination models predict the difference in visibility between two similar images. The models take two images as input, and output a prediction of the number of Just Noticeable Differences (JNDs) between them. In this version of the model, one luminance image is considered to be a blurred version of the background image and the other is the blurred background-with-crack image. These images are filtered using the Contrast Sensitivity Function (CSF) in order to normalize sensitivity. The model takes the contrast energy in the target and adjusts it by the background variance.

#### *Model Calibration*

To provide a common data set for the development of models of contrast target detection, the Modelfest project developed a set of 44 images, most of which are various grating patches (the entire set of 44 calibration images can be obtained from <http://vision.arc.nasa.gov/modelfest>). To calibrate our model, we chose seven of the 44 images because of their physical similarity to aircraft crack defects. These seven images are shown in Figure 2.

Earlier predictions of real world stimuli (Rohaly et al., 1997; Ahumada & Beard, 1997) have assumed a contrast sensitivity function (CSF) with a sinusoidal grating threshold of 1%. To fit the average ( $n=16$ ) Modelfest thresholds for the stimuli in Figure 2 we need to use a best grating threshold of 0.5%. We tried Minkowski summation exponents of 2 and 4 and found that the best fit for these seven stimuli was a

summation exponent of 2 (Euclidean Distance). When the entire set of 44 images was run through the model, the best fitting exponent was 4 (probability summation). This is probably because many of the other images in the set of 44 contained extended, high spatial frequency features whereas the seven images used here either were localized within a small spatial area or contained only extended low frequency energy.

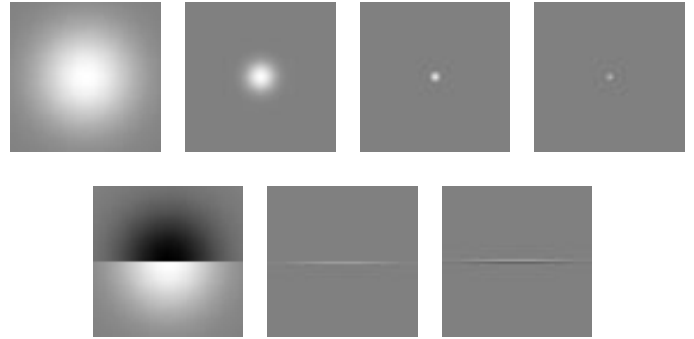


Figure 2. Stimuli used to calibrate the contrast discrimination model. The leftmost 4 images are Gaussians with decreasing standard deviations, the fifth through seventh images are an edge, line, and dipole respectively.

#### *Simulating Visual Acuity Decline*

Although the shape of the human blur function differs between individuals and changes for different optical conditions, it can be approximated by a Gaussian spread function. The model has a difference of Gaussians contrast sensitivity function with a center Gaussian spread of 2 min. To simulate different levels of visual acuity, we blur the image with a Gaussian and then report the acuity as the ratio of the effective center spread to the original model value. Thus we are assuming that the model has 20/20 vision. For example, if the blur has a spread of 2 min, the effective center Gaussian spread will be root 2 times 2 min (Pythagorean rule) so that the effective acuity will be 20/28.



### Model Predictions

We next predicted the visibility of a set of simulated cracks as a function of blur (simulating visual acuity declines) for a range of lengths and widths. The widths were 0.5, 1, 2, 4, and 8 min. The lengths were the widths times 1, 2, 4, 8, and 16. Figure 3 shows how the threshold contrast for each image varied as a function of blur relative to the threshold for the unblurred image. The top curve is the result for the pinpoint crack (e.g., 0.5 min x 0.5 min). The threshold for this image is more affected by blur than the threshold for any other image. The figure shows that if the allowed sensitivity degradation were 6 dB (a factor of 2 in contrast), the allowable acuity degradation would be about 20/60.

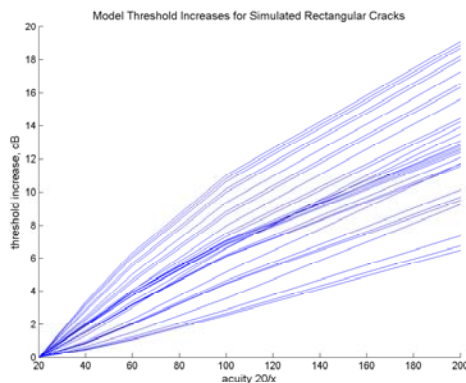


Figure 3. Increments in contrast thresholds in dB as a function of visual acuity decline for the range of crack length and widths described in the text. The top curve is for the smallest crack (0.5 min by 0.5 min), the bottom curve is for the biggest crack (8 min by 128 min).

### DISCUSSION

The first aim of this paper was to describe a methodology that may be used to generate empirically based occupational vision standards. It does not provide a standard, but it converts the problem to specifying a desired physical limitation in performance. Here we use this technique to help define the

spatial vision requirements for aircraft NDI/NDT personnel using simulated crack images. These modeling results will help define the parameters tested in the human psychophysical experiments. We next need to validate that line detection predicts actual aircraft crack detection.

Vision is a fundamental component of effective aircraft maintenance inspection. All the same, so too are other cognitive factors such as attention, memory, and experience. Inspectors are knowledgeable about individual components as well as the overall aircraft being inspected, thus they possess the background to properly locate, identify, and evaluate aircraft defects. Therefore, although vision is a critical component in inspection, other factors weigh in heavily on the naturalistic task.

### ACKNOWLEDGMENTS

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# AN ANALYSIS OF THE VISUAL DEMANDS ASSOCIATED WITH AVIATION MAINTENANCE INSPECTORS

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**Background:** Aircraft maintenance inspectors spend many hours searching for defects in aircraft. Vision guidelines exist for NDI/NDT personnel, but not for visual inspectors. A detailed task analysis is required before job-relevant vision guidelines can be developed. This study is a descriptive investigation of the visual tasks of aviation visual inspectors. **Methods:** Visual inspectors at aircraft maintenance facilities were observed performing inspections on commercial aircraft. Various measures of the visual tasks were recorded. **Results:** On over 900 fixations during inspection procedures, working distances of 50 cm or less were recorded 60.6% of the time. Intermediate distances (>50 cm to 1 m) comprised 27.7% of the working distances. The mean age of inspectors at these locations was 44.7 years. **Conclusions:** The primary duty of visual inspectors is the identification of defects in aircraft when viewed at near and intermediate distances. Data from this study support the need for nearpoint visual acuity requirements.

## INTRODUCTION

Visual inspection is an important component of aircraft maintenance. The National Transportation Safety Board (NTSB) has cited the failure to identify visually detectable corrosion, cracks, or inclusions as the probable cause of several aviation accidents (1989, 1990, 1998). In addition, visual inspection is an important component of Non-Destructive Inspection (NDI) and Non-Destructive Testing (NDT) procedures. NDI/NDT personnel must use their vision, with or without various aids, to make gross judgments, as well as when inspecting aircraft using highly sophisticated imaging and scanning devices (e.g., borescopes, ultrasonic scans, eddy current imaging, X-ray). Inspectors within aircraft maintenance facilities can have primary responsibilities within visual inspection or within NDI/NDT areas. In a recent survey of maintenance facilities, 52% of inspectors were classified solely as visual inspectors, 36% were classified as visual and NDI/NDT inspectors, while only 12% were classified solely as NDI/NDT inspectors (Nakagawara et al., 2003).

While guidelines exist for vision standards for NDI/NDT personnel, no such guidelines exist for visual inspectors. Because of the intimacy between the two inspection classifications (i.e., visual vs. NDI/NDT), most facilities use similar testing requirements for the two types of inspectors. The two jobs are inherently different, however, in terms of the visual task and sophistication of testing equipment.

To the greatest extent possible, vision standards should ensure that workers have the necessary visual skills to perform job-relevant tasks in an efficient and safe manner. For NDI/NDT inspectors, vision skills

should be adequate to identify areas of concern (i.e., detect) and to evaluate (i.e., decision) these areas as to whether further action is required (Drury, 2001). Although the NDI/NDT personnel have many tools to aid in the detection of defects (e.g., fluorescent penetrant and magnetic particle inspections, eddy current and ultrasonic devices, borescopes, magnification aids), simple visual inspection may account for up to 80% of all inspections (Goranson and Rogers, 1983).

As to what constitutes the minimum acceptable vision for an NDI/NDT inspector is difficult to determine. In terms of visual acuity, the standard should be based upon the angular size of the smallest detail for which detection is required.

Rummel (1998) generated probability of detection (POD) curves using NDT procedures to standardize testing by NASA for the space shuttle system. This led to the use of an anomaly size of 1.3 mm (0.05 inches) as the 90 / 95 level that operators performing special NDT procedures must detect 90% of the time with 95% confidence. In a POD study, Spencer and coworkers (1996) had inspectors visually identify cracks in an out-of-service Boeing-737. In this study, the 90% detection point was found for cracks around 0.3 inches. This value is much larger than the 90 / 95 value (i.e., 0.05 inches) for NDI/NDT specialty procedures. The authors also state that for the visual inspection, the length of the crack, crack width, contrast, and inspector accessibility all affected detection performance. These data suggest that calculation of a minimum acceptable visual acuity limit is difficult given the many variables involved. Defect length, width, and contrast, light level, as well as viewing distance are all factors contributing to the

visual acuity demand of a given defect. In none of the studies mentioned, did the researchers attempt to manipulate, restrict, or document viewing distances. With a greater viewing distance, a defect of a given size subtends a smaller angle, and hence will have a greater visual acuity demand.

Drury (2001) analyzed the visual task for inspections in terms of identifying a signal from background noise. He concluded that the greater the strength of the signal (visibility of the crack), relative to the noise (background detail), the more likely it is that detection will occur (for an on-site inspection). Relative signal strength can be increased by decreasing the viewing distance (crack subtends larger angle to the observer), ensuring a focused retinal image (proper correcting lens for the specific working distance), or by improving the quality (eliminate glare) and quantity (increase illumination) of light on the search area. Additionally, just as performance is enhanced by increasing target size and contrast above threshold levels, requiring better vision than that predicted from a direct calculation of minimum target detail is advisable whenever possible. This is particularly important when considering the “sensitivity decrement” that is found with extended searching times especially when finding defects are relatively rare events, a phenomenon known as “vigilance decrement” (Mackworth, 1948).

Since 1988, the FAA has funded numerous human factors projects for Aviation Maintenance Technicians (AMTs) and Inspectors (Johnson and Watson, 1999). These projects were intended to increase the efficiency and accuracy of work performance. For NDI/NDT personnel, contributions were made in the development of “Good Practices” for several inspection procedures (Drury 1999, 2001, Drury and Watson, 2000). Additionally, several studies have documented the essential tasks of Aviation Maintenance Personnel (AMP) (Adams et al., 1999, Allan 1970). These studies provided beneficial data for job-related curriculum development at AMT schools and provided excellent human factors guidance to increase job accuracy and/or efficiency. The studies failed to document, however, measures of visual detail and working distances, which are required to develop job-relevant vision standards.

For an inspector over 50 years of age, the lack of accommodation can greatly affect nearpoint searching. Bifocal lenses can provide appropriate focus for a given working distance, for example at 16 inches with a +2.5 diopters (D) reading addition. For a normally-sighted inspector, with vision correctable to 20/20, these bifocal spectacles would allow for passage of the present Air Transport Association Specification 105 standard. Should such an inspector be restricted to a viewing distance of 32 inches, however, the search area would be 1.25 D out-of-focus in both the distance

and near portions of his spectacles. He would now be inspecting the aircraft with reduced visual acuity, estimated to be 20/50 to 20/60. The FAA deals with this situation for pilots older than 50 years of age and over by requiring the ability to see 20/40 or better at both 16 and 32 inches (Nakagawara and Wood, 1998). This age-related requirement is based upon the need for pilots to see cockpit instruments at intermediate distances and the physiological finding that active focus ability deteriorates with age.

A detailed task analysis, with documentation of required working distances and visual detail dimensions, is not present in the aviation literature for NDI/NDT and visual inspectors. This type of vision-related task analysis is required for these inspectors before a job-relevant vision standard can be developed. This study is a descriptive investigation of the visual task performance of aviation visual inspectors.

## METHODS

The research protocol was approved by the Institutional Review Board of the Ohio State University. Visual inspectors at two aircraft maintenance facilities were observed as they performed visual inspection duties on various types of commercial aircraft (B727, B737, B767, A320, DC8, DC9, MD80). Various measures of the visual tasks were recorded along with the specific auxiliary materials used (i.e., flashlight, magnifier, measuring rule) during inspection procedures. Visual inspection tasks were divided into two categories depending upon the main focus of the procedures. These categories were termed “buy back” and “primary” inspection tasks.

**Buy Back Inspections.** Inspections were termed “buy back” when inspectors checked jobs individually completed by AMTs. These tasks were very specific and generally involved repair or replacement of individual parts or aircraft components. Many involved the inspectors reviewing the AMT’s job card for repair descriptions at an inspection station before traveling to the AMTs work bench or aircraft section. During the inspection, the observer would record the fixation distance, fixation direction, the illumination on the viewed component, specific auxiliary equipment used, and inspector body position (as described further below). A buy back inspection would typically last only 30 to 60 seconds but could last as long as a few minutes when a complicated visual inspection was necessary.

**Primary Inspections.** Primary inspections were those tasks where workers checked general areas during the initial phases of maintenance to identify specific types of defects identified on work cards. Overall these inspections could last between several minutes for

small jobs to several hours for inspections of large areas. For these inspections, observers would record visual measures at specific time intervals. For example, in most locations, the researcher would record the specific fixation distance and direction every thirty seconds. This technique would generate 120 visual data points for every hour of inspection. When a defect would be found, a description of that specific defect would additionally be recorded. If the inspector was scanning an area at the specific moment when the observer recorded activity, several fixation directions and/or distances could be recorded under a single measure.

For both inspection types, observers indicated the primary viewing direction and fixation distance while observing inspectors performing inspections. Up was marked when the object of regard (OR) was above the level of the eyes, down was marked when the OR was between eye level and the waist, and full down was marked when the OR was below the inspector's waist. The distance measures were in centimeters and corresponded to 0.5 units of inverse meters (diopters). Body position was also indicated as follows: Bent Over, Kneeling, Sitting, and on "All Fours." Ambient light level was measured, and the use of a flashlight (FL), a mirror (Mir), or a magnifier (Mag) was also noted. Furthermore, the relative size of visual detail that the inspector was evaluated qualitatively using the following criteria: C = coarse, M = medium, and F = fine. The distributions of these measures (i.e., fixation distance and position) were compared between inspection types using chi square analysis.

Finally, a voluntary survey including demographic and refractive error correction information (e.g., glasses, contact lenses, refractive surgery) was distributed to NDI/NDT and visual inspectors at the various maintenance facilities.

## RESULTS

Data included in these analyses were from 2 maintenance facilities. The mean age of inspectors responding to the survey administered at these facilities was  $44.4 \pm 7.8$  years ( $n = 86$ ). Approximately 30% of surveys were returned. Of those inspectors responding to the survey, 60.5% reported wearing spectacles, 7.0% reported wearing contact lenses, and only 3.5% reported having refractive surgery. Of the respondents, 40% reported never wearing refractive correction. Of those wearing spectacles, 57.7% reported wearing single vision lenses, 9.6% reported wearing traditional bifocals, 23.1% reported wearing progressive bifocals, 1.9% reported wearing trifocals, and 1.9% reported wearing double bifocals. Of those wearing contact lenses, 80% reported wearing soft lenses and none of these lenses were reported as being bifocal or monovision lenses.

The distribution of fixation distances and directions for buy back and primary inspections for over 900 recorded fixations are shown in Table 1. Also included in this table are the inspector reported fixation distances.

Fixation Distance	Buy Back Inspection (Percent)	Primary Inspection (Percent)	Overall Inspector Reported (Percent)
Near	80.2%	58.1%	76.3%
Inter.	8.3%	30.2%	17.8%
Far	11.5%	11.7%	5.7%
Fixation Position	Buy Back Inspection (Percent)	Primary Inspection (Percent)	
Up	21.5%	24.7%	
Down	62.0%	49.7%	
Full Down	16.5%	25.6%	

**Table 1. Distribution of fixation distances and positions for buy back and primary inspections as measured by observers and reported by inspectors.**

For both types of inspection, visual detail was often viewed at "normal" reading distances (less than 50 cm) and in a normal reading position (slightly below eye level). Chi square analysis showed that the buy back and primary fixation distance distributions were significantly different from one another ( $\chi^2 = 27.3$ ,  $p < 0.001$ ). When these observational data are combined and compared to reported data from the survey (see Table 1), no difference across fixation distances was noted ( $\chi^2 = 5.8$ ,  $p > 0.05$ ). This indicates that these personnel are generally aware of the working distances involved in their inspections, and supports the validity of our findings. Chi square analysis also showed that the distribution of fixation positions were different for buy back and primary inspections ( $\chi^2 = 8.0$ ,  $p = 0.02$ ).

Table 2 lists fixation distances and positions for primary inspections for five different aircraft sections.

Fixation Dist.	External Fuselage	Wing	Engine	Special	Cargo Floor
Near	35.0%	79.3%	63.6%	85.6%	50.0%
Inter.	37.6%	17.0%	29.9%	12.4%	41.9%
Far	27.4%	3.7%	6.5%	2.1%	8.1%
TOTAL	263	188	184	97	198
Fixation Position	External Fuselage	Wing	Engine	Special	Cargo Floor
Up	23.4%	27.6%	37.7%	45.5%	1.6%
Down	41.1%	54.6%	56.3%	48.9%	47.1%
Full Down	35.5%	17.8%	6.0%	5.7%	51.3%
TOTAL	214	163	167	88	191

**Table 2. Distribution (percentages) of job-specific fixation distances and positions for primary inspections.**

Chi square analyses showed the inspections across these five sections to be different for both distance and position. External fuselage inspection appears to be the primary outlier, however, individual comparisons shown in Table 3 indicate that the fixation distance distributions are specific to the areas of the aircraft that are inspected. Shorter fixation distance (< 50 cm) is the most common for primary inspections within four sections of the aircraft at 67.2% (Table 2), but the three ranges of fixation distances are approximately equal at 35% to 37.6% to 27.4% (near, intermediate, far) for the external fuselage.

Job Location	Wing	Engine	Specialty	Cargo Floor
External Fuselage	< 0.001	<0.001	< 0.001	< 0.001
Wing	--	0.004	0.413	< 0.001
Engine	--	--	< 0.001	0.027
Specialty	--	--	--	< 0.001

**Table 3. Chi-square analyses for job-specific fixation distance comparisons.**

## DISCUSSION

The setting of a vision standard shares many similarities with determining the cut score for any ability test. The essential job functions must be identified as well as the consequences of non-performance. While the frequency of task performance is an important element in setting a standard, task frequency cannot always be equated with task importance. It can certainly be argued that within aircraft maintenance, because the consequences of an error are so great, all essential tasks are equally important regardless of frequency of completion.

The majority of inspection work performed by these visual inspectors is done at viewing distances of less than 50 cm. Thus, the essence of this work is the identification of defects at near working distances. Coupled with the extreme potential consequences of missing a defect, the frequency data greatly supports the need for a nearpoint visual acuity standard for visual inspectors.

The argument supporting an intermediate visual acuity standard is also strong. The difference in distribution of working distances between buy back and primary inspections appears to be due to the greater control of the visual task inspectors have during buy back inspections. Inspectors can take more time to position themselves properly to see the point of regard clearly during these inspections. Often the

inspection may be at an AMT's workstation away from the aircraft. As such, a very large percentage of viewing was done in a normal reading position of less than 50 cm (80.2%) and at just below eye level (62%).

During primary inspections, inspectors were required to scan large areas efficiently and effectively. Primary viewing direction and distance were more varied (only 58% were 50 cm or less and 49% were just below eye level) and depended upon the physical positioning of the inspector relative to the observed structures. While only 8.3% of visual work with buy back inspections was done at intermediate distances (>50 cm to 1 m), this value was over 30% of visual tasks for primary inspections. As defects are identified chiefly within the primary inspections, the need for an intermediate visual acuity standard should be based upon this figure. If the defect is not identified initially (i.e., during the primary inspection), a repair with the need for a buy back inspection will not be realized.

Because of our normal physiologic accommodative ability, if a worker under 40 years of age can pass a vision standard at a given distance using normal, single vision glasses, he/she should be able to pass the same standard at all working distances. For workers greater than 45 years, however, specially designed multifocal lenses may be required to allow sharp vision at intermediate and near working distances.

As the mean age of inspectors is about 45 years, a large proportion of inspectors have lost significant natural accommodative power. Eyewear must be designed with viewing distances and directions in mind. Although the majority of fixation directions for both type inspections corresponds to the normal bifocal position (slightly down), much primary inspection activity is directed upward (24.4%) and at intermediate to long viewing distances (42%). Inspectors should thoroughly discuss with their eye care practitioners the variations in object distance and direction required of their jobs. In order to ensure clear and comfortable vision at all working distances, special eyewear designs may be required. Inspectors older than 45 years may require trifocals or progressive addition bifocals (i.e., no-line) to allow clear vision at all required viewing distances.

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# A DEMOGRAPHIC PROFILE OF NONDESTRUCTIVE INSPECTION AND TESTING (NDI/NDT) PERSONNEL: A PRELIMINARY REPORT

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**Background:** Aircraft maintenance relies on nondestructive inspection and testing (NDI/NDT) to ensure aviation safety. The visual capabilities of workers are important elements to efficient inspections. Because worker demographic characteristics are important predictors of many visual measures, a survey within aircraft maintenance facilities was undertaken. **Methods:** Data from nine facilities were analyzed to determine a profile of the NDI/NDT workforce, the type and frequency of procedures performed, and vision screening practices. **Results:** Of 889 NDI/NDT personnel, 99% were male. Job classifications included 52% Visual Inspectors, 36% Visual-NDI/NDT personnel, and 12% NDI/NDT Specialists. Median age was 45 years, and ethnic diversity included 73% Caucasians, 13% Asian-, 7% Hispanic-, 6% African-Americans, and 1% others. Eddy-current inspection was performed most often, while radiographic inspection was performed least. **Conclusions:** Preliminary analysis suggests that the visual capabilities and ophthalmic conditions related to males over 40 years of age should be given special consideration in the implementation of a vision-screening program.

## INTRODUCTION

Continuous maintenance of aircraft and aircraft components using both visual inspection and nondestructive inspection and testing (NDI/NDT) procedures is crucial for maintaining a high level of aviation safety. Visual inspectors are highly qualified individuals who use their vision, with or without optical aids, to make judgments about the condition of aircraft and aircraft components being inspected. NDI/NDT specialists are trained to perform technical procedures and to use sophisticated imaging devices and equipment necessary for conducting a variety of procedures. Visual inspectors and NDI/NDT specialists are often considered to be separate groups. However, some maintenance facilities do not formally distinguish between these groups since, in practice, there is considerable overlap in the tasks they perform and the expertise that is required. The major difference between these workers is that visual inspectors normally inspect the assembled (or partially assembled) aircraft, while NDI/NDT specialists tend to focus on the aircraft's individual components. Regardless of job classification, optimal visual performance specific to the task at hand is perhaps the most important physiological attribute these individuals possess to ensure they perform their job responsibilities well. (NOTE: Except when it is appropriate to do otherwise, this document will refer to

visual inspectors and NDI/NDT specialists collectively as NDI/NDT personnel.)

Although the Air Transport Association (ATA) Specification 105 (2002) recommends a minimum visual performance standard, there is currently no federal policy to ensure that persons performing aircraft maintenance and inspection tasks meet a specific vision requirement. Various industry programs have adopted some form of the ATA Specification 105 recommended vision standard for NDI/NDT personnel. However, the vision requirements set forth in these programs are not standardized throughout the industry, nor are they based on any known visual job-task analysis. An assessment of the visual performance demands placed on NDI/NDT personnel is needed to develop a job-relevant vision standard.

In two important ways, vision standards differ from other human factors as it relates to job success. First, visual performance can be measured quickly, comprehensively, and dependably. Second, when vision performance falls below a desirable level, it can be improved in a majority of cases and at relatively low costs. About 50% of adults in the United States have difficulty seeing distant objects clearly, and about 60% have difficulty seeing up close when no corrective lenses are worn. Research (Kleinsteins, 1993) with subjects using their usual refractive corrections has indicated that the prevalence of impaired distant and



near vision can be as high as 30% and 40%, respectively. These numbers can be substantially reduced when best-corrected visual acuity (BCVA) is provided. One study (Zerbe, 1958) involving over 500 patients (20 to 60 years of age) found that only 6% could not be improved to 20/20 visual acuity with BCVA and fewer than 1% were incapable of 20/30 visual acuity. Therefore, should the presently employed vision standards need to be made more stringent, there should be no appreciable reduction in the current NDI/NDT workforce. An appropriate task-related vision standard would compel workers to obtain proper refractive correction designed specifically for their job responsibilities. Job opportunities may be more numerous for the few workers unable to achieve or maintain a high level of BCVA should research find that a lower level of visual performance is adequate for some inspection activities.

Since a substantial percentage of the general population has impaired vision with their present corrections, a similar percentage of the NDI/NDT workforce may possess less than optimal vision. Kleinstein (1993) found that poor vision reduced the performance and productivity of workers and increased the risk of mistakes or accidents. While the medical costs of workplace injuries due to some vision-related accidents are reported by government agencies and insurance companies, the cost associated with untreated vision disorders in NDI/NDT personnel is not easily assessed. Workplace injuries aside, vision problems present in these individuals could lead to flawed inspections that result in aircraft accidents, injuries, and/or fatalities, as well as financial losses from liability litigation and poor public relations. For example, the National Safety Transportation Board (NTSB) has cited the failure to identify visually detectable corrosion and cracks as the probable cause of the following aviation accidents:

- ➔ Delta Airlines, Flight 1288; July 6, 1996 (NTSB Report AAR/98/01) — A crack with a total surface length of 1.36 inch in the front compressor hub of a Pratt & Whitney JT8D-219 engine was not detected during visual and fluorescent penetrant inspections, which resulted in an uncontained engine failure during takeoff.
- ➔ United Airlines, Flight 232; July 19, 1989 (NTSB Report AAR/90/06) — A crack with a total surface length of 0.498 inch in the stage-1 fan disk of the No. 2 CF6-6 engine was not detected during visual and fluorescent penetrant inspections. The NTSB determined that at least two inspections were performed after the crack had reached a detectable length.

- ➔ Aloha Airlines, Flight 243; April 28, 1988 (NTSB Report AAR-89/03) — The NTSB determined that the cause of this accident was the failure of the Aloha Airlines' maintenance program to detect the presence of significant disbanding and fatigue damage, which ultimately led to the failure of lap joint at stringer 10L. A passenger reported seeing cracks near the door while boarding the aircraft.

A Federal Aviation Administration (FAA) Advisory Circular (AC 43-204), entitled "Visual Inspection for Aircraft" (1997), states that over 80% of the inspections on large transport aircraft are visual inspections. This percentage is even greater for small transport and general aviation aircraft. FAA regulators, including the Aircraft Maintenance Division (AFS-300) and the Aircraft Maintenance Technical Committee Representative Group, have recently expressed concern that the current vision standards adopted by industry may not be adequate for all tasks performed by NDI/NDT personnel, suggesting that more appropriate task-based vision standards should be developed.

This report provides preliminary data that describe the NDI/NDT workforce and procedures performed by three major air carriers (nine facilities) in the United States. Once complete, information provided in this study will be used to help establish appropriate vision standards based on the visual demands of NDI/NDT procedures.

## METHODS

A survey is being conducted that includes gathering data on the type and frequency of NDI/NDT procedures performed at major aircraft maintenance and manufacturing facilities in the United States. Demographic and procedural information was gathered by soliciting responses to a survey questionnaire submitted to supervisory personnel at three major U.S. air carriers serviced by nine separate maintenance facilities (Note: For the sake of anonymity, the three airlines in this survey were assigned the designations Airline A, Airline B, and Airline C). The requested data includes the number, classification, and other pertinent information necessary to describe the NDI/NDT personnel populations at these facilities, the type and frequency of NDI/NDT procedures performed, and the current vision screening practices these facilities employ.

## RESULTS

**FIGURE 1: WORKFORCE DISTRIBUTION**

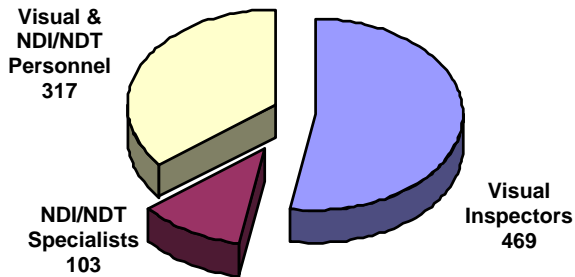


Figure 1 shows the population frequency, by job classification, for the 889 NDI/NDT personnel surveyed. The job classification percentages represented are 52%, 12%, and 36% for Visual Inspectors (n = 469), NDI/NDT Specialists (n = 103), and Visual-NDI/NDT personnel (n = 317), respectively.

**TABLE 1: WORKFORCE FREQUENCY & AGE**

Airline	Facility	Employees	Age Range	Median Age
A	1	304	35 – 65	47
	2	96	30 – 62	37
B	3	135	39 – 67	45
	4	185	32 – 76	53
C	5	42	30 – 64	45
	6	13	40 – 70	62
	7	43	25 – 64	45
	8	58	22 – 65	35
	9	13	35 – 62	45
<b>Total</b>		<b>889</b>	<b>22 – 76</b>	<b>45</b>

Table 1 provides the number of employees, minimum and maximum ages, and median age of NDI/NDT personnel by facility. The median age for the survey population was 45, with an age range of 22 to 76 years.

**FIGURE 2: WORKFORCE DIVERSITY**

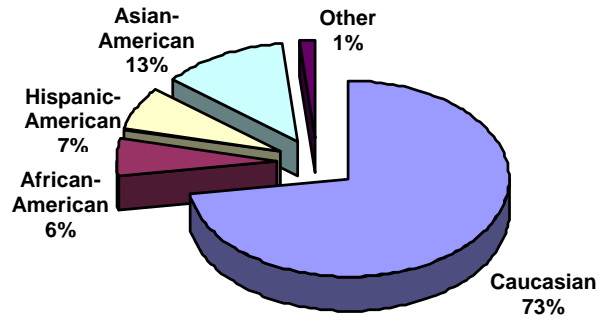


Figure 2 illustrates the percentage of NDI/NDT personnel surveyed at all facilities by cultural ethnicity. The percentages represented include 73% Caucasians (n = 645), 13% Asian- (n = 113), 7% Hispanic- (n = 62), 6% African-Americans (n = 55) and 1% other (n = 14) ethnic cultures present in the survey population. In addition, males comprised 99% (n = 880) of the NDI/NDT employee population surveyed.

**TABLE 2: NDI/NDT PROCEDURE RANKING**

Procedures	Rank
Eddy Current	1
Fluorescent Penetrant	2
Borescope	3
Ultrasonic	4
Magnetic Particle	5
Radiographic	6

Table 2 provides the cumulative ranking of the NDI/NDT procedures (1 = most often performed; 6 = least often performed) identified in this survey. Four facilities provided rankings, which were weighted by the proportion of personnel who performed these procedures and summed to provide a cumulative rank for each procedure. The results indicate that personnel at these facilities most often performed eddy-current inspection, while radiographic inspection was least often performed.

Vision standards employed by each of the three airlines surveyed (Airline A, 1994; Airline B, 2000; Airline C, 2002) were at least as stringent as the ATA Specification 105 recommendations.

## DISCUSSION

The population demographic data collected to date for NDI/NDT personnel describes a relatively homogenous collection of individuals. The majority of the workforce is male (99% vs. 55% in the US: Note: US statistics are based on data obtained from the Bureau of Labor Statistics, <http://www.bls.gov>, June 2003, for employed males  $\geq 20$  years of age) and Caucasian (73%), with a median age of 45 years (vs. 41 years in the US: M. Di Natale, Bureau of Labor Statistics, written communication, June 2003). NDI/NDT inspectors, in this preliminary study, are older than their colleagues who perform only visual inspection duties. This may be due to seniority preferences for NDI/NDT positions in unionized facilities.

Conducting NDI/NDT procedures tends to be a more sedentary activity, often performed in a controlled environment. Conversely, the duties of a visual inspector often requires more physical prowess, calling for a considerable amount of standing, walking, climbing, bending, and crawling into tight spaces. Visual inspections are usually performed in a hangar environment or in the ramp area. The median age and age range of visual inspectors at different sites varied widely and may depend on a number of factors, including seniority preference for particular jobs, geographical location, and when the facility was built and staffed. For example, at older facilities where unions are prevalent, senior employees may request and be granted more desirable positions and work schedules. At facilities established more recently, employees are generally younger, and seniority may have less of an impact on staff positions.

Differences between visual inspector and NDI/NDT specialist operations vary according to the policies of the particular maintenance facility and/or airline. In some aircraft maintenance facilities surveyed, NDI/NDT and visual inspection activities operate almost independently. While in other facilities, both NDI/NDT and visual inspection personnel are combined into a single department under a common administrative staff. In these facilities, NDI/NDT personnel may do visual inspections, but not all visual inspectors are qualified to perform NDI/NDT procedures. In other words, specific job responsibilities are more a function of the individual's training and experience, rather than his/her specific employee classification.

There are few females employees (about 1%) in the NDI/NDT personnel population. The lack of females in the inspection population is probably because many candidates for NDI/NDT positions come from the ranks of those who started out as mechanics or other maintenance-related positions at these facilities. Traditionally, these occupations have been male dominated, which appears to explain the shortage of female NDI/NDT personnel found in this survey.

The NDI/NDT population appears racially diverse as indicated by Figure 2. While, in the facilities surveyed to date, the majority of the workforce is Caucasian (73% vs. 72.7% in the US), Asian (13% vs. 3.8% in the US), and Hispanic (7% vs. 12.4% in the US) employees represent substantial percentages, followed closely by African-Americans (6% vs. 8% in the US). To some extent, the differences in ethnic diversity for individual facilities appear related to the ethnic diversity of the general population where the facility is located. For example, in the California facilities surveyed, there are considerably more Asians employed as NDI/NDT personnel than there are in facilities surveyed that are located in areas where this ethnic group makes up a smaller percentage of the general population. According to the US Census Bureau's, Annual Demographic Supplement to the March 2002 Current Population Survey (2003), 51% of the Asian population in the US live in western states compared to 19% for non-Hispanic whites.

The most frequently performed NDI/NDT procedure is eddy-current inspection, and the least often performed procedure is radiographic inspection in the facilities surveyed to date. As indicated in Table 2, fluorescent penetrant, borescope, ultrasonic, and magnetic particle inspections were ranked second, third, fourth, and fifth, respectively, in frequency of performance at these facilities. However, individual facilities may not follow this ranking schedule if they specialize in the maintenance of a specific aircraft component or system. For example, survey responses indicated that, while eddy-current inspections were most prevalent at facilities that perform primarily airframe maintenance, the most frequent NDI/NDT procedure performed in power-plant (engine) maintenance facilities was fluorescent penetrant inspection. Dissimilarities in the procedures performed at different facilities may complicate development of uniform vision standards. For example, the visual demands of eddy-current inspections, which require reading relatively large displays, are less than those

necessary to detect tiny cracks when performing fluorescent penetrant inspections.

Vision testing procedures differed between the three airlines surveyed, suggesting that a more consistent procedural methodology should be developed. Additional research is ongoing to identify the vision requirements associated with the most visually demanding tasks performed by these workers. Once task-based visual performance requirements are properly assessed, appropriate vision standards and screening procedures can be developed.

## CONCLUSIONS

Preliminary analysis suggests that employee job classification may be less of an indicator of visual performance requirements than the actual NDI/NDT inspection procedures being performed by these individuals. In addition, since the median age of the subject population is greater than 40 years of age, the combination of presbyopia and vision loss normally associated with age-related ophthalmic conditions should be a consideration in the development and implementation of a vision-screening program. Given that the population sample was made up of predominately male Caucasians, gender differences and ethnicity may need to be considered to a lesser extent when evaluating the vision performance characteristics of the current NDI/NDT personnel population. Special focus on the tasks necessary to competently execute the most visually demanding inspection procedures appears warranted. Once complete, this research will help determine the appropriate vision standards and screening procedures for initial qualification and re-qualification of personnel responsible for performing visual and NDI/NDT inspection of aircraft and aircraft components. Technical and advisory documents identifying vision testing equipment, procedural requirements, and preferred refractive corrections that may be advantageous to those performing specific job tasks will be additional benefits of this research.

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## COMPUTER AND BROADBAND TECHNOLOGY IN THE AVIATION MAINTENANCE WORKPLACE

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We surveyed the marketplace for computer and broadband technologies and investigated their use at eighteen aircraft maintenance facilities. We documented the use of technology at maintenance facilities through field notes gathered during site visits and telephone interviews. We found deployment of technology at every maintenance facility we surveyed. The extent of technology deployment was determined by size of the company, financial resources, and type of operations. The goal of technology deployment, at every facility, was to reduce operations costs by making more efficient use of existing maintenance resources. Feedback about the technology in use sometimes differed strikingly between managers and maintenance technicians: managers' comments were characterized by cost concerns, while maintenance technicians' comments were largely based on learnability and practical usability of the technology.

### INTRODUCTION

As aircraft maintenance organizations recognize the potential cost-savings offered by technologies that store and communicate information in digital format, tech companies have rushed to the marketplace to meet the demand. We researched the marketplace of computer and broadband technologies now offered to aircraft maintenance facilities. Through a series of site visits and telephone interviews, we documented the use of these technologies at eighteen aircraft maintenance facilities.

The following is a summary of a large collection of field notes we gathered during those visits and interviews. We have organized our findings around the kinds of technologies that are now offered. We begin with the most basic of the technology products: digitally-archived documents, and progress our way to the cutting-edge: wireless-networked, wearable computers.

For each type of technology, we discuss:

- 1) How and why the technology is used
- 2) Maintenance facilities that use the technology
- 3) Feedback received from both managers and maintenance technicians about their experiences with the technology.

### SOFTWARE TECHNOLOGIES

The first category of aircraft maintenance technology we encountered was software products used to provide managers and technicians with access to documentation, and status information about maintenance work happening within the company.

We identified three kinds of software technologies offered for aircraft maintenance applications:

- 1) Electronic documentation
- 2) Maintenance scheduling/tracking/inventory systems
- 3) Systems built on top of scheduling/tracking/inventory systems

#### Electronic Documentation

The most basic type of software technology digitally archives and manages the revision process for aircraft maintenance documents. These documents include: maintenance manuals, illustrated parts catalogs, and job cards (cards that spell out specific maintenance procedures).

Electronic documentation represents the foundation, or bottom layer, of the available technology.

#### Uses:

In its most basic form, electronic documentation is stored on a central database where it is maintained, revised, and updated on schedule. Maintenance technicians access the documentation through a variety of computer hardware devices, all described below.

In addition to providing basic access to documents, advanced features of the electronic documentation systems cross-reference related sections of the electronic maintenance manuals and illustrated parts catalogs, check for updates, and then print job cards that integrate relevant text and graphics drawn from multiple electronic documents.

These features streamline the mechanic's job of gathering paperwork to complete a maintenance task.

*Vendors:*

Jouve Aviation Solutions is a major supplier of electronic documentation products. Jouve's AirGTI DocManager acts as an intermediary between equipment manufacturers and the maintenance facilities that operate and service the equipment. We found Jouve systems in use at eleven of the eighteen maintenance facilities we interviewed.

Some individual aircraft manufacturers, such as Boeing and Bombardier, offer their own products. Boeing's BOLD (Boeing On-Line Data) system offers all of the same kinds of documents, including service bulletins and parts lists, for the Boeing fleet. We found several facilities using these products, sometimes in addition to the Jouve Aviation products.

Electronic documentation proved to be the most widely-accepted and deployed type of technology. We found electronic documentation being used at every maintenance facility we contacted.

*Feedback:*

We received positive comments about electronic documentation from everyone we interviewed. There seemed to be universal agreement about the benefits of electronic documentation among both managers and maintenance technicians. Interviewees cited specific reasons cited for their favorable attitudes toward electronic documentation:

- (1) Technicians liked how the computer allowed them to open several documents at once – something not achievable flipping through pages of a paper manual.
- (2) Technicians liked how related documents were often linked. This represented a significant time savings over having to search through tables of contents and indices.
- (3) Managers stressed the ease and frequency that they were able to accomplish updates and revisions. The plug-and-play capabilities of the computer enables them to do updates every 14 days.
- (4) The time required to accomplish updates and revisions is now hours instead of days.

**Maintenance scheduling/tracking/inventory systems**

A second type of software technology helps to manage all aspects of maintenance work, for

individual aircraft, company wide.

*Uses:*

This technology computerizes:

- 1) Scheduling of future maintenance checks, or delayed MEL items.
- 2) Scheduling of maintenance personnel.
- 3) Ordering and inventory of parts
- 4) Life expectancy and actual life of parts
- 5) Hand-off of maintenance work from one crew to another.

This type of software management system is capable of coordinating the collocation of aircraft, needed parts, and maintenance personnel, at a scheduled place and time.

*Vendors:*

Hundreds of companies offer work management and scheduling software. Aviation Maintenance [1] published a review of the state-of-art systems offered as of 1999. Two systems we encountered frequently were MRO Software's Maximo product, and Sabre Technology Solution's Maxi-Merlin system.

*Feedback:*

The feedback we received from managers was overwhelmingly positive, as these systems automate many of the tasks required to coordinate a maintenance effort.

Maintenance technicians were somewhat indifferent toward this type of technology, and focused more on the practical aspects of the interface between maintenance worker and the computer that implemented the system. They sometimes complained about the computer interfaces being older or lacking in usability. Maintenance technicians typically mastered the specific functions they needed to use and paid little attention to the rest of the system.

**Systems built on top of scheduling/tracking/inventory systems**

A third type of technology we encountered were systems that had been built on top of existing scheduling/tracking/inventory systems. These systems use the core features of a scheduling/tracking/inventory system and extend its features.

One company we visited has made significant investments in this type of technology. One customized system in use displays a graphical map of all aircraft on ramp and their status. These displays are located in the ramp controller's tower on the

airport. An air-to-ground communications system (discussed below) allows airplanes to communicate with the ramp controller. The displays feature a color coding scheme that allows controllers to quickly scan an entire ramp and assess the status of all aircraft (e.g., Red = aircraft taxiing; Blue = engines lit, beacon on).

The same company is developing a number of systems that will provide paperless aircraft logs, video conferencing capabilities, and video training aids. None have been implemented at this time.

This company is also exploring the idea of a system that will archive case-based troubleshooting tips for maintenance incidents. Their prime concern is that the age distribution among maintenance technicians will result in a loss of a significant proportion of their experienced workforce. Such a system would help preserve expertise in the company as expert technicians retire in numbers.

### **HARDWARE TECHNOLOGIES**

The second category of aircraft maintenance technology we encountered was hardware devices used to provide managers and technicians with access to the software systems described above.

#### **Computer workstations**

The most basic type of hardware system we found were computer workstations that are typically located on the shop floor.

##### *Uses:*

Computer workstations were used almost exclusively by maintenance technicians and inspectors. Workstations typically have printers connected to them, allowing technicians to print out pages and carry them to the aircraft.

##### *Feedback:*

The feedback we received from maintenance technicians about the computer workstations was generally positive:

- 1) Technicians liked how the workstations support multiple users. When several workstations are available, there is no need to wait to access a single paper copy of a manual.
- 2) Technicians mentioned the time spent walking back and forth between workstation and aircraft.
- 3) When only a few workstations were available, technicians sometimes had to wait to access the needed documentation, in the same way they did when paper manuals were used.

#### **Portable/wearable computers and wireless networks**

The most advanced type of hardware technology was the portable or wearable computer that communicates with a central server via a wireless network. The wireless network consisted of a central computer and a series of RF antennas placed around the worksite to permit line-of-sight communications between central computer and portable computer anywhere on the ramp or shop floor.

We encountered three kinds of portable computers:

- 1) Laptop computers
- 2) Personal data assistants
- 3) Pen-based tablet computers

Some computers include harnesses that allow them to be worn, keeping the technicians' hands free to do work.

##### *Uses:*

The most basic use of the portable computer was as a vehicle for the electronic documents described above – maintenance manuals, illustrated parts catalogs, etc. One major airline carrier we interviewed gave portable computers to their line maintenance inspectors who did walk-arounds on arriving aircraft. The computers are used to write up and quickly distribute squawks.

Portable computers also provide technicians with access to the scheduling/tracking/inventory systems described above. Technicians can make log entries, fill out work cards, send and receive maintenance alerts, and communicate with other technicians.

##### *Vendors:*

Xbernaut Corporation offers the Xbernaut Mobile Assistant. Via Incorporated offers the Via II PC. Several companies offer personal data assistant (PDA) computers. We found none of the custom-made wearable computer systems [2, 3] in use at any facility we visited.

##### *Feedback:*

Portable computers and wireless networks represented the most diverse comments we received from managers and maintenance technicians.

Managers were enthusiastic about the technology and seemed to be impressed by the technological capabilities. A quote from one company manager summed up a popular complaint among many companies: "We can't get our guys to use them."

Maintenance technicians often complained about their portable computers. One line maintenance

technician pointed to an idle laptop computer sitting on top of an aircraft tug and said: "I never touch the thing." Specific complaints about the portable computers included:

- 1) The wireless RF networks were often intermittent. When the RF network didn't function, the whole system was unusable.
- 2) Wireless networks still offer slow transfer rates. Multiple users often compete for signal, and transfer rates are degraded.
- 3) The screens on the portable computers were often too small or offered too low of a resolution.
- 4) Batteries often ran out at inconvenient times.
- 5) The portable computers had durability problems when subjected to hard use on the shop floor. More rugged computers are available but at much higher cost.
- 6) Less 'computer savvy' technicians find them difficult to learn and use.

Some maintenance technicians were very opposed to the idea of replacing computer workstations with portable computers (e.g., "Don't you dare take it away from me.")

One company surveyed the attitudes of their maintenance technicians toward portable/wearable computers. They found that 16% of technicians rated the computers "easy to use," while a total of 59% found it at least "acceptable." 75% of technicians said they would consider using the device.

Positive comments from maintenance technicians about wireless networks were that it enabled problems to be forwarded to maintenance facility for immediate action when aircraft land.

### **Other Wireless Technologies**

We encountered a few other kinds of wireless communications networks.

#### *Cockpit computers*

Spirent Systems offers an Onboard Maintenance System that provides real-time fault detection on board an aircraft in flight. The OMS is capable of detecting faults that are not presented to the crew in the form of alert messages. For example, each pitot tube contains two heating elements. The crew will not see a NO PITOT HEAT message unless both heating elements become inoperative.

One airline has installed server computers on board its aircraft that can store electronic documentation as well as data collected from an Onboard Maintenance System. Their system contains an interface that pilots can use to make

inputs and entries.

#### *Cockpit to floor*

The same airline has implemented a wireless local area network technology that allows the servers installed in the airplanes to communicate with ground servers once the aircraft is parked and the doors are disarmed. Once a connection is established, the ground server updates the aircraft maintenance manual and the flight operations manual as required. The aircraft server then downloads the flight manifest and any fault information registered by the Onboard Maintenance System or the crew.

#### *Air-to-ground*

The existing ACARS system is used by some carriers to transmit fault information to the company ground servers while an aircraft is still in flight. This allows line maintenance crew to be prepared when any aircraft lands. One company reports that their air-to-ground communication system avoids roughly 90 delays per year.

One corporate aircraft maintenance facility related a story of a Gulfstream G-V, flying at FL510 over the Pacific Ocean, that experienced a windshield crack. The maintenance facility located the needed windshield at a west coast facility, arranged for technicians to be on the ground at the airplane's ETA, and then directed the aircraft to that facility, where the work was completed with minimum ground time.

The stated goal of all of the air-to-ground wireless technologies is "to eliminate unscheduled maintenance."

### **CONCLUSION**

We found computer and broadband technologies in use at all eighteen aircraft maintenance facilities that we surveyed. We found the available technology to be offered in layers, allowing maintenance facilities to gradually implement new systems on their own schedules. We found a wide interesting in implementing computer and broadband technologies, as well as large and growing number of vendors that offer the technologies.

The comments we received suggest that the deployment of technology has been driven by management in an effort to cut operations costs.

The feedback we received from managers and maintenance technicians we generally positive, with one exception: managers were enthusiastic about portable and wearable computer systems, whereas, maintenance workers were not. Managers' comments were driven by concerns of company-wide costs, while technicians were concerned with practical usability of the computers.



Perhaps the most striking feature of the comments we received was that there was little discussion of how computer and broadband technologies impact or relate to *safety*. In no case did a maintenance technician make reference to any technology helping them find or resolve a maintenance problem that they would not have found or resolved otherwise. Rather, the technology was seen as an aid to more efficiently and economically using their existing maintenance resources.

We searched for the character string “safe” in all documents we collected, including: magazine articles, presentations, product information sheets, and our interview notes. Only one product information sheet contained the word “safety.”

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# **EVALUATION OF BROADBAND APPLICATIONS TO AIRCRAFT MAINTENANCE SAFETY: A CASE STUDY OF GOODRICH AVIATION TECHNICAL SERVICES**

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In an effort to better understand the use of broadband technologies in the aviation maintenance environment, the researcher investigated the use of broadband technologies, electronic manuals, Portable Display Units (PDAs), and electronic scheduling at Goodrich Aviation Technical Services. The question was: how do state-of-the-art of broadband applications affect maintenance operations? The researcher gathered information about the broadband technologies used at Goodrich and discussed the advantages and disadvantages of these technologies with Goodrich personnel. Increased efficiency was the main advantage gained from using broadband technologies, whereas the biggest disadvantage was cost.

## **INTRODUCTION**

The goal of this research is to help gain an understanding of the human factors issues pertaining to the integration broadband technology into the maintenance environments. In particular, to identify the advantages and disadvantages in using portable display units, electronic manuals, and electronic scheduling in the aviation maintenance work environment. To do this, the researcher gathered product information for various broadband applications and discussed advantages and disadvantages of these applications with Goodrich Aviation Technical Services personnel.

Headquartered in Everett, Washington, Goodrich Aviation Technical Services provides maintenance and repair to over 400 airlines. Currently, with over 2,600 employees, it is the North America's largest independent aircraft maintenance provider, servicing more than 500 aircraft per year. Goodrich offers a full-range of maintenance services, including: Aircraft modifications, passenger-to-freighter conversions, heavy airframe maintenance, component repair and overhaul, engineering and certification, and aircraft painting.

## **BROADBAND TECHNOLOGIES**

### **Electronic Manuals**

In the past, mechanics had to wade through mountains of paper or microfilm to get the

maintenance information they needed. Not only was this process tedious, it was difficult to keep the information updated.

Goodrich uses Boeing On-Line Delivery or (BOLD), which is a service that provides digital maintenance manuals, structural repair manuals, and manufacturer drawings from a central database. BOLD is a web-based application, and requires only a personal computer with a standard internet connection to use.

There are numerous advantages to using electronic manuals. Before the implementation of BOLD, countless hours were spent updating paper and/or microfilm documents. BOLD is updated on a daily basis. And since BOLD is issued through a central server, it is easy to ensure employees have access to the latest revision of each manual. The time formerly spent updating manuals can now be more wisely used on the hangar floor.

Computer kiosks with access to BOLD are readily available throughout the hangar floor. In addition, BOLD can be used for more than maintenance manuals; service bulletins, maintenance tips, in-fleet reports and other documents are available through the service. In the future, more features will be added, such as product standards and detailed technical drawings. Also, self-paced training programs may be accessed through BOLD.

In addition to BOLD, Goodrich also has manuals for private and foreign operators on a local server in standard Adobe pdf. format.

However, there are a few disadvantages of using BOLD. First, Employees need training in how to use the system. Though this can be a relatively quick and painless process for those comfortable with computers, it may take a little longer for those who are not computer savvy. Second, in some cases, the electronic documentation may not be as easy to read as paper documents (for example, certain highly detailed documents, such as system schematics). There is also the issue of personal preference. Some employees may just *prefer* working with paper documents and be unhappy about making the switch to computers. Lastly, is the issue of cost. To implement BOLD, an organization must subscribe to the service and also purchase enough computers to allow the material to be readily accessible to the employees.

### **Portable Display Units (PDAs)**

In an effort to reduce downtime during heavy maintenance checks, Goodrich implemented Perceptive Solution's Handheld NRC 2.0. Perceptive tailored the program to meet the requirements and specifications of Goodrich. These wireless hand-held devices offer a number of advantages over the traditional paper-and-pencil process.

In the past, the first part of a heavy maintenance check involved time-consuming paperwork and data entry. First, inspectors would conduct their inspections based on the customer's maintenance program. Non-routine maintenance items would be hand-written onto the specific customer's forms. Then, the customer's forms would be entered into a computer. From there, Goodrich and the customer would talk about the non-routine items and come to an agreement on which items should be completed. This procedure left plenty of opportunity for human factors errors, both from errors in filling out the forms and in data entry.

The new process, using PDAs, allows inspectors to generate work orders right on the hangar floor. The

major advantage of using the PDA rather than writing out work orders by hand is speed. Each PDA is programmed with commonly used non-routine maintenance items, which the inspector can pick and choose from.

The program maximizes efficiency and virtually eliminates errors of omission by leading the inspector through a series of programmed procedures, the non-routine maintenance item paperwork is actually being created *while* the aircraft is being inspected. As soon as the inspection is finished, the inspector merely pushes a button on his PDA, sending the document via radio-transmission directly to the computer system. Once in the computer, leads and supervisors can access it, allowing the work to begin immediately. Rather than having to wait for all of the paperwork to be written up and entered into the computer by a data entry person, the mechanics can go right to work.

For the first time at Goodrich, mechanics can actually be working on the non-routine items before the inspection is even completed. Because the lag time has been eliminated, it is estimated Goodrich has been able to shave 16 hours off a typical 40-hour inspection.

One drawback of using PDAs is that training is necessary. Goodrich let inspectors take the PDAs home to become familiar with them, and allow them to practice the specialized handwriting necessary to operate one. After two or three weeks, most inspectors seemed comfortable using the PDAs, and within a few months, all of the inspectors were proficient and seemed generally satisfied with their PDAs. Another issue is cost. The cost of implementing Perceptive Solutions' Handheld NRC was about \$500,000. However, with the increased efficiency gained from implementing the system, it can be argued this cost will be recouped in the future.

### **Electronic Scheduling Tool**

Goodrich uses Open Plan, an "off the shelf" electronic scheduling tool. Open Plan is similar in format to Microsoft Project. Since a typical D-check (complete structural overhaul) is complex and

usually involves 160 mechanics, 1,500 work orders, and thousands of manhours, Open Plan offers the tremendous benefit of tracking and organizing the entire process.

To customize the scheduling tool for Goodrich's purposes, they asked their maintenance experts to analyze a typical D-check, and break it down into individual activities needed for successful completion. Then, estimates for completion time were calculated for each activity.

Supervisors are able to track 800 to 1,300 activities in an aircraft maintenance schedule. Activities are listed in order of importance, with the most critical activities at the top of the list. Also, each activity has an estimation of the time it will take to be completed. Supervisors assign work cards, which list various maintenance duties, to mechanics. Leads must input a start and end time for each activity. This allows the schedule be analyzed and updated continuously. If the progress on an aircraft falls behind schedule, management is alerted with an electronic notification. This allows managers to shift resources to the stalled aircraft to help get it back on schedule.

Maintenance activities can also be organized by work type (e.g., painting) and all work of that particular type can be scheduled for a certain day.

The biggest advantage to using the electronic scheduling tool is increased efficiency. Before the implementation of Open Plan, a D-check took about 37 days. Now, it only takes about 27 days. This time saved means cost savings for Goodrich. Using Open Plan has streamlined the entire maintenance process so that time is no longer wasted due to lack of coordination.

Another benefit of using Open Plan, is that it gives customers a chance to check on the status of their aircraft. Using the internet and a password, customers can get a current report of their aircraft. Armed with the knowledge of precisely when the aircraft will be ready, they are better able to plan future flights for the aircraft.

Like any new program, Open Plan requires user training, although it is relatively easy to learn. Another issue to consider is the cost of the program, which was about \$500,000.

## **CONCLUSIONS**

The broadband technologies used by Goodrich offer many advantages over traditional methods. Electronic manuals, Portable Display Units (PDAs), and electronic scheduling have all led to increased efficiency. The greatest drawback is the cost of implementing these technologies.

# Appendix II

## Human Factors Aviation Maintenance Research Requirements

Below is a list of requirements that pertain to the projects listed in Appendix I

### Research Requirement

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[An Evaluation of Broadband Applications to Aircraft Maintenance Safety](#)

[Language Barriers Result in Maintenance Deficiencies](#)

[Using Technology to Support Inspector Training](#)

[Vision Testing Requirements for Certain Persons Maintaining  
and Inspecting Aircraft and Aircraft Components](#)

### Below is of FY04 requirements

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[An Assessment of Barriers to Implementation of Aviation Safety  
Action Programs \(ASAP\) in Maintenance Organizations](#)

[Auditing and Surveillance Maintenance Error Web-Based Tool](#)

[Effects of fatigue/vigilance/environment on inspectors performing  
Fluorescent Penetrant and/or Magnetic Particle Inspections](#)

[General Aviation Alaska Maintenance Accidents](#)

Requirement ID: 889

Sponsor Organization: AFS-230

POC: Tom Longridge

Requirement Title: An Assessment of Barriers to Implementation of Aviation Safety Action Programs (ASAP) in Maintenance Organizations

Funded Requirement:

- FY02: No
- FY03: Yes
- FY04: Yes
- FY05: Yes

Requirement Statement: The goals of the project are as follows: 1) To determine the human factors issues involved in ASAP, 2) Identify barriers in implementation of ASAP, 3) Perform benchmarking studies of maintenance facilities that use ASAP to determine the best practices in the industry, and 4) To determine the best methods for reporting, documenting, and analyzing human factors issues surrounding maintenance errors identified via ASAP.

Background: As safety programs and tools sponsored by FAA continue to evolve, the maintenance community continues to struggle with their use and applicability. The Aviation Safety Action Program (ASAP) is one example of a program that was initially created for use by flight operations organizations within air carriers, then adapted for use by maintenance organizations. This adaptation has been less than successful, and has resulted in a low number of maintenance organizations using ASAP. This research initiative will address why current ASAP programs do not adequately support the management of maintenance error through exclusion of certain risks existent in the maintenance system, highlight the difficulty with comprehensive fixes, and validate the difficulties encountered when entering into "voluntary" programs with the regulator.

Output: Final report identifying why ASAP is often not implemented in the maintenance industry and a discussion of methods for overcoming these barriers. This report will also recommend possible solutions to aviation maintainers' concerns about ASAP that have already been expressed, e.g., voluntary disclosure and self-disclosure overlap. In addition, the report will compare and contrast ASAP programs to determine which practices work best and provide guidance to the best methodology for collecting and utilizing human factors ASAP data.

Regulatory Link: none

Requirement ID: 864

Sponsor Organization: AFS

POC: Les Vipond

Requirement Title: An Evaluation of Broadband Applications to Aircraft Maintenance Safety

Funded Requirement:

- FY02: Yes
- FY03: Yes
- FY04: Yes
- FY05: No

Requirement Statement: To determine the extent to which human-centered design contributes to the successful application of emerging technologies that include, but are not limited to: training-on-demand, video-on demand, wireless access to technical documentation and much more. This research shall review the emerging technologies to the extent to which such technologies are impacting safety<sup>370</sup>

Background: Identification of emerging broadband applications to maintenance. Identification of safety impact of broadband technology. Assessment of positive and potential negative impact of broadband applications for maintenance technicians. An understanding of the integration between training and job-aiding as broadband technology use in maintenance environments.

Output: Overview of the state-of-the-art of broadband applications to maintenance. Identification of safety impact broadband applications for maintenance technicians. An understanding of the integration between training and job-aiding as broadband technology using maintenance environments.

Regulatory Link: none

Requirement ID: 922

Sponsor Organization: AFS-300

POC: Les Vipond

Requirement Title: Auditing and Surveillance Maintenance Error Web-Based Tool

Funded Requirement:

- FY02: No
- FY03: Yes
- FY04: Yes
- FY05: Yes

Requirement Statement: develop existing PC /paper based auditing/surveillance tool to web-based application in performing auditing/surveillance/monitoring and validation of oversight of maintenance to ensure a consistent level of oversight is maintained. This system can proactively identify contributing factors of improper maintenance before aircraft is dispatched once work is complete. In addition, portions of this web-based surveillance/auditing tool can be used by aircraft manufacturers before delivery of aircraft to their customers.

Background: Several attempts have been made by FAA and industry to standardize error mitigation tools. Industry typically revises these tools to meet their own organizations' system, hence trending data across industry is difficult. Recently NTSB and a large manufacturer expressed interest in developing an existing PC and paper-based process used by large air cargo company to a web-based application. This web-based tool will help airlines, repair stations, air cargo, and manufacturers ensure compliance with FAA approved Continuous Airworthiness Maintenance Program. Development of this web-based application is to promote an environment of continuous improvement and team work by performing and documenting a variety of intentional and systematic surveillance oversight activities/inspections that make sure FAA regulations, airline, air cargo, and repair stations policies and procedures, and aircraft manufacture's maintenance procedures are complied with. This oversight is to insure that each aircraft dispatched is safe, airworthy, reliable and regulatory compliant. The web-based surveillance tool should incorporate findings from the following: a) In Process Surveillance, b) Verification Surveillance, c) Final Walk Around, d) Aircraft Walk Around, e) Quality Control, f) Inspection, g) Technical Data Control, h) Shelf Life Control, i) Tool/Test Equipment, j) Housing & Facilities, k) Safety/Security/Fire Protection, l) Storage, m) Work Processing, n) GMM Compliance, o) IPM Compliance, p) Fuel Surveillance, q) Description/Findings, r) Corrective Action/Follow up, s) Monitoring changes to and the accuracy of maintenance personnel, verifying that additions and recurrent training meet the requirements, and t) Airworthiness Directive Verification.



Output: De-identified web-based auditing/surveillance tool to be used by airline industry, air cargo, repair stations, manufacturers, and FAA. Results of surveillance and monitoring will correct or improve performance deficiencies. Findings can be shared by manufacturers, airlines, repair stations and air cargo's to help identify and prioritize factors that transcend across industry to foster elimination of these types of errors that are contributors /precursors and could systematically eliminate or reduce potential errors. Development of web-based system will meet Certification Process Study Finding 1 and Certification Process Implementation (CPI) Plan. Development of web-based system should be completed by December 2003 to meet goals of Certification Process Implementation (CPI) Action Plan. In addition, results of surveillance could be used to proactively disseminate lessons learned to industry and enable air carriers, manufacturers, air cargo and repair stations to identify potential errors when performing maintenance.

Regulatory Link: Certification Process Study and Certification Process Implementation Plan; NTSB recommendation

Requirement ID: 920

Sponsor Organization: AFS-300

POC: Rusty Jones

Requirement Title: Effects of fatigue/vigilance/environment on inspectors performing Fluorescent Penetrant and/or Magnetic Particle Inspections

Funded Requirement:

- FY02: No
- FY03: Yes
- FY04: Yes
- FY05: Yes

Requirement Statement: As a result of the National Transportation Safety Boards investigation into the July 6, 1996, uncontained engine failure in Pensacola, Florida, of Delta Air Lines flight 1288, a McDonnell Douglas MD-88, Safety Recommendation A-98-17 was issued to the FAA. This safety recommendation requests that the FAA, “conduct research to determine the optimum amount of time an inspector can perform nondestructive testing inspections (NDI) before human performance decrements can be expected.” A research project studying NDI as a whole is very expensive, time consuming and hard to quantify, however the two primary methods of NDI that lend themselves to such a study are Liquid Penetrant and Fluorescent Magnetic Particle Inspection.

Background: Inspectors performing these two methods are expected to scan wide areas of critical parts looking for small defects. The inspector viewing these parts must work for extended periods of time in a dark room using ultra violet light to accomplish these inspections. It is well documented that the probability of detecting small defects decreases as time on the job increases. Does the working environment; i.e. working in the dark, low expectation of finding critical defects, further magnify this vigilance decrement for inspectors performing Liquid Penetrant or Fluorescent Magnetic Particle Inspections?<p>

Conduct empirical research to study the effects of fatigue/environment on the vigilance decrement of inspectors who perform Liquid Penetrant or Fluorescent Magnetic Particle Inspections as their primary work function. Determine the optimum time that can be realistically spent performing these two inspection methods before detectability is significantly decreased.

Output: A “Best Practices” document to inform the aviation community of the potential problems associated with fatigue in combination with environment when performing these two inspection processes. This can serve to educate the NDI community, and emphasize the need for regulating the time and individual spends performing these processes.

Regulatory Link: The National Transportation Safety Board (NTSB) issued Safety Recommendation A-98-17 as a result of the Delta/Pensacola accident.

Requirement ID: 918

Sponsor Organization: AFS-300

POC: Les Vipond

Requirement Title: General Aviation Alaska Maintenance Accidents

Funded Requirement:

- FY02: Yes
- FY03: Yes
- FY04: No
- FY05: No

Requirement Statement: NTSB data and the generally high GA accident rate in Alaska indicate that this issue must be studied to determine if the overall accident rate can be reduced by reducing the maintenance error rate if maintenance issues are determined to be a significant issue in Alaska accidents.

Background: Determine the role of maintenance in the high general aviation (GA) accident and incident rate in Alaska. Review for the last 10 years NTSB and FAA GA accident and incident data for the entire country to determine the leading maintenance factors that contribute to GA accidents and incidents for aircraft operating both in Alaska and the rest of the country. Compare the Alaska data to the maintenance contribution accident data for the rest of the U.S. Using this data, determine if maintenance errors are a contributing factor or a direct causal factor to accidents to a greater degree in Alaska than in the rest of the country. If data indicates maintenance errors have a greater contribution to accidents in Alaska when compared to the rest of the U.S., determine the particulars. Error classification factors present in Alaska may include: 1)Extreme climates, 2)Limitations on Parts and equipment availability, 3)Aging aircraft fleet, 4)Severe operational demands, and 5)General lack of other maintenance resources.

Output: Research report, and documentation required to support development of advisory circulars or safety related training on CD or video to be used by the FAA Safety Program.

Regulatory Link: Parts 91, 43, 121, 135, 145

Requirement ID: 862

Sponsor Organization: AFS

POC: Les Vipond

Requirement Title: Language Barriers Result in Maintenance Deficiencies

Funded Requirement:

- FY02: Yes
- FY03: Yes
- FY04: Yes
- FY05: No

Requirement Statement: To determine whether the growing number of maintenance and inspection personnel who possess a wide range of non-native English reading, writing, and speaking abilities are more inclined to commit an error than personnel whose native language is English.<sup>253</sup>

Background: The existence of maintenance and inspection personnel whose native language is not English suggests that language barriers may be causing performance errors. Within the airline maintenance environment there is an increasing trend towards outsourcing. Phillips (2002) in Aviation Week and Space Technology notes "...the move by airlines to slash costs is driving outsourcing to new levels." In a related paper, Sparaco (2002) sees the formation of global MRO (Maintenance and Repair Organizations) networks involving US and foreign airlines as well as repair stations. In addition to offshore MROs, there are many within the USA where non-native English speakers form part of the labor pool. There is an increasing population of non-native English speakers, some of whom can be employed as mechanics or inspectors. Again, the difficulty of moving between languages creates an additional potential for error. An earlier report on human error in repair stations from the FAA's Human Factors in Maintenance and Inspection initiative also showed the trend toward outsourcing (Drury, Wenner and Kritkauskys, 1999). What did not emerge specifically from this report was that many Part 145 facilities are not located in the USA, creating some potential for errors where the staff does not have English as their native language. The language of aviation is primarily English, both in operations and in maintenance. An Aviation Maintenance Technician (AMT) must pass their examinations in English, and all maintenance documentation in use at the Federal Aviation Administration (FAA) approved facilities is in English. This poses a second-language or translation burden for Non-Native English Speakers (NNESs) that can potentially increase their workload, their performance time or their error rate, or even all three measures. In a 2001 report to the Secretary of Transportation by the Aircraft Repair and Maintenance Advisory Committee, many of these issues were raised in considering changes to the domestic and foreign FAR Part 145. The issues concerned the qualifications and standards for personnel, makes one conclusion: "Although new Part 145 requires supervisors, inspection personnel, and personnel authorized to approve an article for return to

service to be able to read, write and understand English, there is some concern that communication, particularly with regard to the ability to speak English, may be a problem in foreign repair stations. However, there is no data to indicate that there is a problem in this area.” and a recommendation (Drury, Wenner, and Kritkauskys, 1999) that: “The FAA should establish a method for determining whether language barriers result in maintenance deficiencies.” This requirement is a direct response to these concerns that NNEs, in repair stations in the USA and abroad, may be prone to an increased error rate that could potentially affect airworthiness.

Output: Final report will provide refined estimates of error frequency, patterns of error types, effectiveness of intervention strategies and recommendations for FAA action to mitigate language related errors

Regulatory Link: Secretary of Transportation requirement (1/29/01)

Requirement ID: 863

Sponsor Organization: AFS

POC: Les Vipond

Requirement Title: Using Technology to Support Inspector Training

Funded Requirement:

- FY02: Yes
- FY03: Yes
- FY04: Yes
- FY05: Yes

Requirement Statement: To demonstrate how advanced technology can be used for inspection training and reducing errors for the general aviation industry<sup>128</sup>

Background: Reduce inspection errors and improve GA inspection performance, ultimately impacting safety and reliability of GA aircraft inspection and GA maintenance operations. · Standardize the GA inspection training process providing an industry-wide benchmark for inspection training. · Alleviate problems inherent to OJT and can be combined with existing GA training programs to facilitate consistency in inspection training, provide adaptive training and support record keeping and performance monitoring.

Output: This research will provide the general aviation industry with a benchmark for inspector training. Evaluation and validation studies will be delivered that focus on the impact of inspector training programs in minimizing inspector errors and standardizing the inspection training process.

Regulatory Link: none

Requirement ID: 801

Sponsor Organization: AFS

POC: Rusty Jones

Requirement Title: Vision Testing Requirements for Certain Persons Maintaining and Inspecting Aircraft and Aircraft Components

Funded Requirement:

- FY02: Yes
- FY03: No
- FY04: No
- FY05: No

Requirement Statement: At a minimum, the goal of this project is to determine the proper standards to be employed in the visual acuity testing of persons inspecting aircraft and aircraft components. This material will then be set forth in an Advisory Circular or eventually be included as an amendment to the Federal Aviation Regulations. This project would involve, as a minimum, the following: 1. Determine vision parameters that include but not limited to: visual acuity, stereo acuity, color vision, peripheral vision, near and far focal length, contrast sensitivity, visual fields, eye disorders, eye diseases, medication effects, corrective lenses, colored lenses, and age effects. 2. Determine who will be required to meet these minimum standards for performance of their job function. 3. Determine the time interval when vision tests will be administered. 4. Establish written procedures to provide guidance to organizations that will need to setup programs for administering and documenting the eye examinations. 5. Determine if these standards should be included in an Advisory Circular or as an amendment to the Federal Aviation Regulations.1138

Background: Over fifty percent of all Advisory Directives issued, require inspection, yet there is no standard to determine how well or if an inspector can see. Part 67 of the Federal Aviation Regulations provides requirements for visual acuity testing for aircraft pilots for first, second and third class medical certificates. There currently is no requirement to assure that persons performing maintenance or inspection of aircraft meet a minimally acceptable vision requirement. Various programs for the certification of persons performing Nondestructive Testing require vision examinations prior to certification. These requirements are neither uniform nor standard throughout the industry. There currently is no requirement for a person performing visual inspections to be tested for visual acuity or color perception. There have been several aircraft accidents where large cracks and/or corrosion were not detected during visual inspections. The National Transportation Safety Board (NTSB) has cited the failure to visually detect detectable cracks as the probable cause of these accidents. Examples of these are as follows: NTSB 98/01, Aircraft Accident Report, Uncontained engine failure, Delta Airlines, Flight 1288, McDonnell Douglas MD-88, N927DA, Pensacola, Florida, July 6, 1996. A crack with a total



surface length of 1.36 inch in the front compressor hub of a Pratt & Whitney JT8-219 engine, was not detected during Visual and Fluorescent penetrant inspections. NTSB 09-06, United Airlines Flight 232, McDonnell Douglas DC10-10, Sioux Gateway Airport, Sioux City, Iowa, July 19, 1989. A crack with a total surface length of 0.498 inch in the stage 1 fan disk in the no. 2 CF6-6 engine was not detected during Visual and Fluorescent penetrant inspections. The NTSB determined, based on a count of the fatigue striations that at least two inspections had been accomplished after the crack had reached a detectable length. NTSB 89/03, Aloha Airlines, Flight 243, Boeing 737-200, N73711, near Maui, Hawaii, April 28, 1988. The NTSB determined that the cause of this accident was the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage which ultimately led to the failure of a lap joint at stringer 10L. This damage should have been detected visually and in fact, a passenger boarding the aircraft visually saw cracks that were not detected by Aloha mechanics.

Output: Determine acceptable vision standards and procedures for personnel involved in nondestructive inspection and testing (NDI/NDT) and visual inspection of aircraft and aircraft components.

Regulatory Link: The National Transportation Safety Board (NTSB) has cited the failure to visually detect detectable cracks as the probable cause of these accidents.